by the same author

MICE, MEN, AND ELEPHANTS

SUBMARINES

PARACHUTES

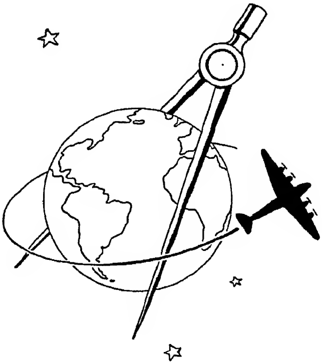
Official U. S. Navy Photograph

LARGE PLANES CARRY A NAVIGATOR WHO KEEPS THE PILOT INFORMED OF THE PLANE'S POSITION

AIR NAVIGATION

by HERBERT S. ZIM

ILLUSTRATED WITH DRAWINGS
BY JAMES MAC DONALD
AND WITH PHOTOGRAPHS



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FOREWORD

AIR NAVIGATION is new, but it has been successful because the methods and instruments were developed by men who knew how to apply basic scientific principles to their immediate problems. Many of these pioneers in air navigation are still the experts of today. Without the help of some of these experts and the organizations they represent, gathering the data for this book would have been a far more difficult task than it was.

For such assistance the author is particularly indebted to the War Department, Bureau of Public Relations, and the U. S. Army Air Forces, Public Relations Branch; the U. S. Navy, Office of Public Relations; the U. S. Department of Commerce, Weather Bureau, for data on meteorology; the Editorial Division of the Weather Bureau for some of the illustrations; the Pan American Airways System, the Pioneer Instrument Division of the Bendix Aviation Corporation, and the Sperry Gyroscope Company for information and illustrations on navigation instruments. The publications of the Civil Aeronautics Administration were most helpful, and special thanks are due to William A. Mehl, Bruce Uthus, and Fred Hamlin of that organization. I am most grateful to Captain Ray W. Wells, Chief Pilot of the Trans-

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For checking the manuscript, I am indebted to Captain Ray W. Wells, to Charles A. Wolf of Pioneer Instrument Division, and to Sergeant Paul E. Lehr, 4th Weather Squadron, Spence Field, Georgia; also to three young enthusiasts, Charles Winkelstein, Richard and Donald Wallach, for valuable suggestions.

HERBERT S. ZIM

New York City
November, 1942

AIR NAVIGATION

1

EVERYONE NAVIGATES

NAVIGATION isn't really very different from walking, eating or getting dressed. We do all of these things daily without much thought. The whole process of getting dressed or eating breakfast is pretty automatic. It is in this same automatic, unconscious way that most people navigate. Navigation is no more than the art and science of getting from one place to another. While the word is frequently used in connection with ships and planes, it is equally true that you can navigate on foot or on a bicycle. More recently the word *avigation* has been used to distinguish between navigation of planes and ships. There are enough differences in instruments and methods to warrant the use of a special word for a new and special branch of an old science.

People are constantly going from one place to another. They usually arrive at their destination—the grocery store, church, or the movies—without any particular trouble. People never give the matter a second thought. You leave your house for the Strand Theatre and in a few minutes you are at the box office. This is no feat of intelligence—yet unconsciously you have been using some of the same principles of navigation that a captain uses on his ship and a pilot in his plane.

The captain or pilot of the plane is just as certain of reaching his destination—whether it be Wake Island, Timbuktu, or New York—as you are when heading for the theater. When a stratoliner takes off from La Guardia Airport for Los Angeles it doesn't land at San Francisco or San Diego by mistake any more than you would land at the butcher's when you start out for the movies. The adventurous among us are almost tempted to regret that navigation always works out so well. That's why flying is not as exciting or as eventful as some people imagine. No one gets excited when things turn out as expected, but it is just that very quality that makes avigation important.

Were avigation only 60% or 70% accurate, then every plane trip would be an adventure. You could not be quite sure if you would hit the airport or a mountain, or if you would land at Columbus, Ohio, or St. Louis, Missouri. Under these conditions, flying might be adventurous, but its real value would be vastly reduced. Without the aid of good avigation, air travel could be nothing more than a sport at best—and perhaps not even a safe sport. As flying has improved so that planes can run on schedule, no matter what the distance or the weather, aviation has come into its own. Nowadays you can count on air travel. Improved methods and instruments help make this possible.

As I said, a trip to the movies involves basic principles of navigation. It does. But you are not very conscious of it. When you moved to a new town you consciously navigated during your first day or so there. You watched the street signs, the landmarks, or perhaps even a town map. You may have had to check your

direction occasionally to avoid getting lost in the strange surroundings. Once you became familiar with the street, directions, and landmarks, your navigation took less and less of your attention. By now you merely go to the movies or the grocery without thinking of it at all.

Yet all the time you are aware of landmarks. You know the movie is just down the block from the department store. Streets and avenues locate less familiar places in the same way that an avigator uses latitude and longitude. You also consider time in your own navigation. It's a five minute walk to the movies, but if you have to stop at the library on the way to return a book, you know just how much more time to allow for the detour. Though you have never stopped to figure it out on paper, the five minute walk to the movies is the result of two factors. The first is your usual walking speed. The second, of course, is the distance. Knowing these two factors you allow yourself five minutes to walk to the movies. Enlarge the distances thousands of times and you are talking in terms of avigation. Knowing the speed of your plane, the distance and destination, you can plot a course that will get you to Nome, Alaska, or Santiago, Chile, just as surely as you reach the movies.

Occasionally in your own navigation around town you resort to "blind flying." Even the heaviest fog wouldn't keep you indoors if you had a date you didn't want to miss. Even if you could not see ten feet ahead, the feeling of the sidewalk, the curb at every corner, and your knowledge of the street patterns would get you where you wanted to go. At home, where you

are even more familiar with your surroundings, you can navigate around the house reasonably well in the dark. Visual landmarks are not essential. You can feel the stair rail or the door knob or the place where the carpet ends. The ticking of the clock in the living room makes a good guide also.

Planes fly by dead reckoning or fly blind. They can frequently neglect visible landmarks and substitute radio signals plus a knowledge of their air speed, drift, and direction. No "blind" navigation, either in a plane or at home, is as easy as seeing where you are going, but there are now many safeguards against the dangers that crop up when the pilot cannot see the details of his course.

The fact that everyone navigates in his own small way does not mean that any person at all can get a plane from one airport to another. The basic principles are the same, but the skill and application needed to navigate a plane are far greater than you need to get around town. Yet if you understand the reasons and methods of navigation, the whole earth becomes as familiar as Main Street, and with the help of the equipment and instruments available to avigators world travel becomes a routine matter, safe and dependable.

Though the science of avigation cannot be mastered overnight, it can be reduced to three basic questions everyone can understand. The avigator must obtain quick and accurate answers to them. Where am I? Which way am I going? How fast am I going? Answer these three questions and there is not much left to avigation. Yet these three simple questions may be exceed-

ingly difficult if not impossible to answer satisfactorily. In a fog with no landmarks visible, "Where am I?" may become a question of life or death. But even then, with the proper instruments, the question may still be answered with reasonable accuracy. Of course, the compass tells direction, and most of the time a glance at the compass card will answer the question "Which way am I going?". But you will soon find out that even this is not a simple matter. Nor is the question of speed. Air speed and ground speed may be very different. Winds may produce peculiar effects that make the determination of true speed a difficult question in a plane.

Navigation is no more than the art and science of getting where you want to go. It is fast becoming an important, essential part of our daily lives because people are traveling faster and farther year after year. Air travel has pushed back the frontiers of the world. Present-day air speeds make the vehicles of a generation ago appear as slow as snails. It is these modern speeds—up to 300 miles per hour—that have made accurate avigation so important.

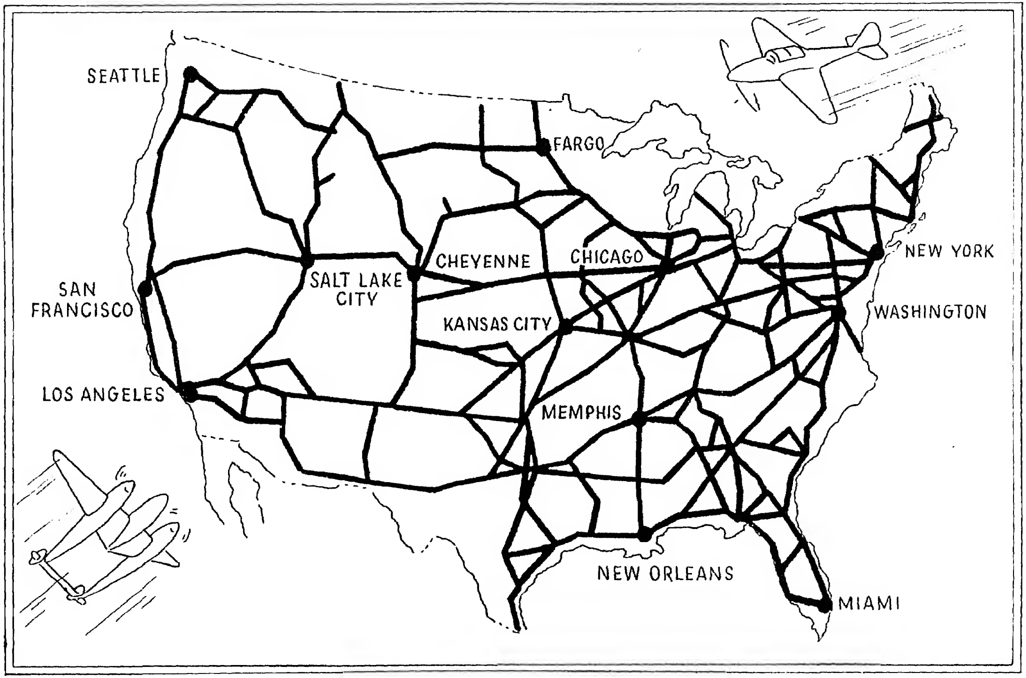
On that fateful day in December 1903, when Orville Wright first flew a motor-powered plane a few hundred feet, he had no need for navigation. He and his brother were too concerned with getting their invention to work. But the next flight was a bit longer and soon a plane could stay in the air for a whole hour. In 1909, Louis Bleriot flew across the English Channel. A year later George Chavez flew across the Alps. In the fog and mists of the Alpine peaks, air navigation became impor-

tant. Soon there were pioneer transcontinental flights. On an early one, Robert C. Fowler landed his plane after dark with the aid of a lantern set on a bed sheet. This was the forerunner of the modern airport. His plane had only the simplest of instruments and Fowler avigated by following the railroad tracks—as modern pilots still do.

But thirty years have produced miraculous changes. Howard Hughes flew across the United States in 7½ hours. The Atlantic Clipper reached Lisbon in 18 hours' flying time from New York. About 40,000 miles of commercial air routes cross and recross our country. There are nearly 3,000 landing fields of all types. About 3,000,000 passengers travel the airlines each year. Besides this tremendous growth, military aviation has increased, doubling and redoubling in size. There are more and more private planes and pilots. Whatever the future holds, we can be sure that planes will have an essential part in our daily lives.

The increased size and speed of planes put an additional burden on the pilot. There is no time to observe landmarks at leisure. At high speeds, a slight error in direction will soon mean a large distance off course. The efficiency of a plane depends in the long run on the skill with which it is navigated.

Boats and trains travel on a two-dimensional surface. Because of this obvious fact they are easier to navigate. For airplanes, the third dimension—altitude—is all important. Navigation of planes is constantly concerned with distance above the ground as well as horizontal distances. When a pilot inquires, "Where am



MORE THAN 30,000 MILES OF LIGHTED AIRWAYS CROSS AND RECROSS THE UNITED STATES

I?" he must know how high he is above the ground as well as his relation to landmarks. Determining the elevation of the plane above the ground is fairly difficult, especially when the altitude of the plane is changing.

The ocean of air can be more tempestuous than the sea. Weather is still an important and uncontrollable factor in flying. No pilot will ever be able to control the weather, but every flyer must understand it and must try to outguess the clouds and the winds. Every bit of knowledge that enables the meteorologist or the pilot to predict the weather is a further aid. Every scrap of data that eliminates the unknown factors of weather is a help. Once weather conditions are known they may be considered in computing distance and direction. Allowance can be made for wind, cloud, or snow.

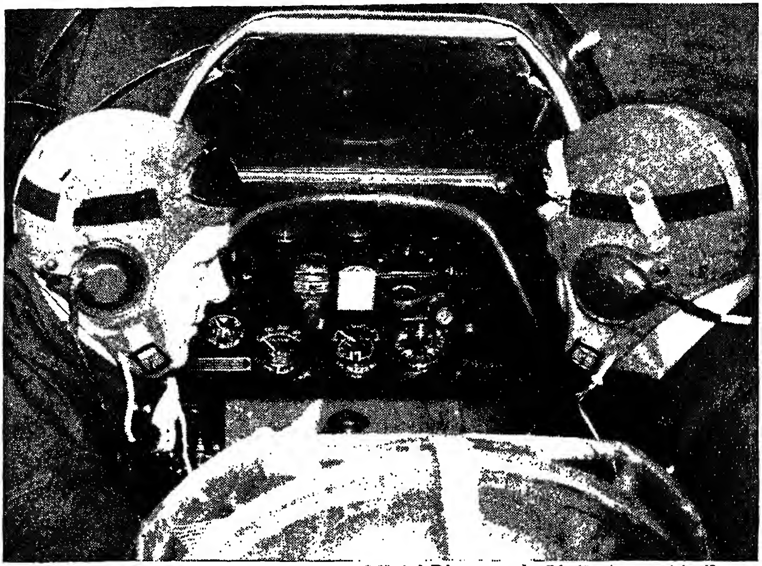
In a way, knowledge helps tame the weather and makes it just another factor in flying. Unknown weather conditions or sudden undetected changes in weather are a constant danger to ships riding in the sea of air. That is why air navigation is so concerned with weather maps, radio weather reports, and with weather forecasting. That is why pilots must know the meaning of clouds and wind. Planes nowadays fly in weather that a few years ago would have grounded everything. The weather has not become milder or more constant, but improvements in planes, in weather forecasting, and in avigation have made flying much safer in what otherwise might be called stormy weather.

Avigation is both an art and a science. The science part is basic. It supplies the tools, the instruments, the facts and tech-

niques. The art of avigation is the application and use of these instruments, charts, and other aids in plotting a course and getting the plane over it on schedule. The art of flying comes largely from practice and it develops with experience in the air. But the scientific background can be acquired without leaving the ground. You can understand about avigation, about the instruments and methods, long before you actually fly. You can go farther and practice flight problems on the ground similar to those a pilot must solve while in the air.

Even for a trained pilot, navigation is more than checking position, speed, and direction after the take-off. Much of the work must be completed before the pilot enters the plane. There will always be a lot of ground work because avigation is essentially setting up a plan of travel and then trying to stick to it. Setting up the plan is the ground work. It must be thorough. Maps and charts must be studied with the fuel load, speed, and other characteristics of the plane in mind. Special attention must be given to the weather. With this information a course is plotted and a flight plan made. Once the plane is off the ground, the job is to follow the planned course, making adjustments to changing weather. If the basic plan is at fault, it may be too late to make major corrections.

Navigation of a plane is necessarily a responsible job. It is so important that the study of air navigation is included in the training of every pilot. To be sure, you could fly a plane and know nothing of avigation. You could even get around a bit by watching local landmarks and staying within sight of the air-



Official Photograph, U. S. Army Air Forces

FROM THE BEGINNING OF HIS TRAINING THE PILOT LEARNS TO USE THE NAVIGATION INSTRUMENTS

port. But for all real flying some navigation knowledge is essential. You may even become an expert in the subject if you wish. Military and trans-oceanic planes often carry a navigator who has the sole responsibility of getting the plane to its objective and back again. On smaller planes and on commercial lines, where there is a definite route, each pilot navigates for himself. The exact amount of avigation knowledge needed for each flying job cannot be predicted exactly. However, it is safe to say that no pilot ever suffered from knowing too much

about navigation and many have deeply wished they knew more.

There is no sharp distinction between the work of a pilot or an avigator. One can assert that piloting is mainly getting the plane up and keeping it there. Avigation is mainly getting where you want to go. But practically the two tasks merge into one important job.

Navigating a plane makes a number of assumptions that are true most of the time. It assumes, for example, that the plane is airworthy and will travel if given the usual amount of attention. A pilot who is trying to repair a leaking gas line or keep his plane out of a tail spin must put aside thoughts of avigation for the moment. Avigation further assumes that the pilot is going somewhere and wants to get there the shortest, safest, and quickest way. The student practicing turns over the airport is not concerned with avigation—not until he starts to fly cross country and has a destination. Granting this, anyone with good eyesight and hearing can learn to avigate. So, if you can see, hear, and are interested in planes and flying, you are all set to tackle avigation from the very beginning.

2

INSTRUMENTS AND METHODS

THERE are many kinds of navigation, from the simple, unconscious type we automatically use every day to the complex systems using the latest instruments and mathematical methods. It is not a question of one method being better or more advanced than another. Rather it is a question of suiting the method of navigation to the problem. It would be just as foolhardy to trust landmarks on an ocean voyage as it would be to use a sextant to find the nearest hardware store.

Distinct differences between avigation and navigation exist, though the underlying principles are similar. It is the speed and altitude of the plane that makes this so. On a boat a navigator gets his bearings by taking observations on two stars. During this operation the ship has sailed only a mile or so. For practical use the observations can be treated as if the ship were stationary. If the same observations were made from a plane, the position may have changed from ten to twenty-five miles in the same few minutes. Different calculations are needed.

The avigator often sees the world beneath him as a huge map. If visibility is clear, he has many landmarks in view from which to judge his position. On a ship landmarks are harder to see and navigation must be more accurate. The captain can slow

down if conditions at sea become bad. Riding out a storm may only be a question of time. But the pilot does not have this advantage. Once in the air he must go on. He must calculate the farthest point from which he can safely turn back. He must allow reserves of fuel in case fog or storm make landing impossible. Time is always running against the pilot.

The type of avigation and the instruments used (if any) depend on the length of the flight, the size of the plane, the experience of the pilot, and the weather conditions. Some navigation instruments are too costly, too heavy, and too complicated for use in a small private plane. These same instruments are essential in a huge bomber or transport.

Many people think that the bigger and more complicated an instrument is the better. This need not be so and the instrument board does not have to be loaded down with dials in order to navigate a plane. A small plane taking short trips can manage perfectly well with a minimum of equipment. You will get the point if you ever have seen a small cheap car loaded down with gadgets. There seems to be at least one such jalopy in every town. The owner has the windshield, bumpers, and body covered with all kinds of devices; turn indicators, fancy horns, a variety of signal lights, numerous signs, and a lot of chromium trimmings. But the car itself probably has no brakes or piston rings. These same gadgets might be in place and even useful on a powerful 16-cylinder roadster, but on the jalopy they only indicate poor judgment and wasted money.

Instruments of avigation may also be gadgety. Each has its

correct place and should be used there. The essential flight instruments and methods are simple. You might overlook their importance just because you take them for granted.

To come right down to the simplest and best aid to avigation, consider the matter of landmarks: any prominent features that aid a pilot in determining where he is. Flying with the aid of visible landmarks is the simplest and best method. Once you learn to recognize landmarks, either natural or man-made, you can immediately establish your position.

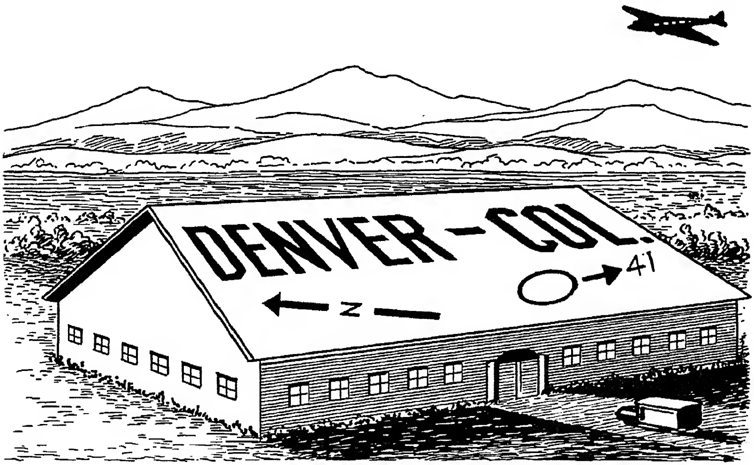
There are many types of landmarks that the pilot learns to know. A good landmark must be prominent and easily seen from the air. It should be distinctive and not confused with anything similar. Finally there must be landmarks at short enough intervals so the pilot may constantly keep them in sight. In most parts of this country such landmarks are easy to find and an experienced pilot recognizes landmarks that another might miss. Even the dry plains, deserts, and mountains have distinct natural landmarks that are helpful in determining position.

Natural landmarks are often easiest to notice. In some places a river makes an excellent course to follow. From the air an isolated hill may be visible fifty miles away. Cliffs, lakes, islands, points of land, changes of terrain, and even differences in vegetation may serve as air landmarks. To understand and recognize these natural landmarks a pilot may study physical geography. Knowing the nature and forms of rivers and mountains aids in their recognition.

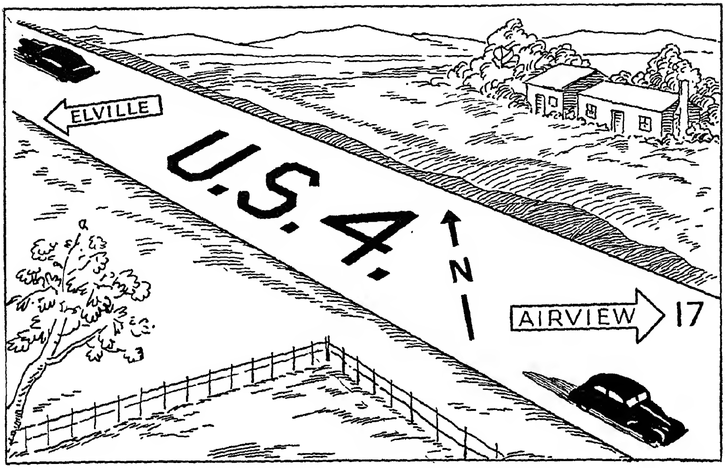
Man-made landmarks may be more important to the pilot

than natural ones. The pilot is probably headed for an airport and the airport is usually near a town. The pilot must recognize both. Railroads, highways, electric transmission lines, canals are sure things for the pilot to follow, if he can identify them. Besides these man-made ribbons, there are many isolated landmarks—buildings, water towers, monuments, radio stations, reservoirs, race tracks, and other structures distinctive from the air. Besides there are the special landmarks built to aid the pilot.

You have undoubtedly seen a building with a large arrow painted on the roof. Often the name of the town is also there. Huge directional signs are sometimes painted on highways, too, marking the highway number and the direction. Such mark-



MARKERS ON BUILDINGS SHOW THE PILOT HIS POSITION AND DIRECTION



MARKED HIGHWAYS ARE GUIDES FOR THE NAVIGATOR

ings are as helpful to the pilot as are roadsigns to the motorist. There is a standard system of markers. For towns that have an airport, the marker includes the town name, an arrow pointing north, and a symbol showing distance to the airport. The symbol is a circle with an arrow pointing to the airport. A number at the arrow's tip gives the distance. At towns without airports, markers are outline arrows with the name and distance of the nearest airport. In addition there is a north arrow and the town's name.

There are about 3,000 airfields of all types in this country. All are carefully marked and may be identified from the air. The major air routes are marked with beacons and markers that enable the pilot to determine his position accurately.

Courtesy of Civil Aeronautics Administration

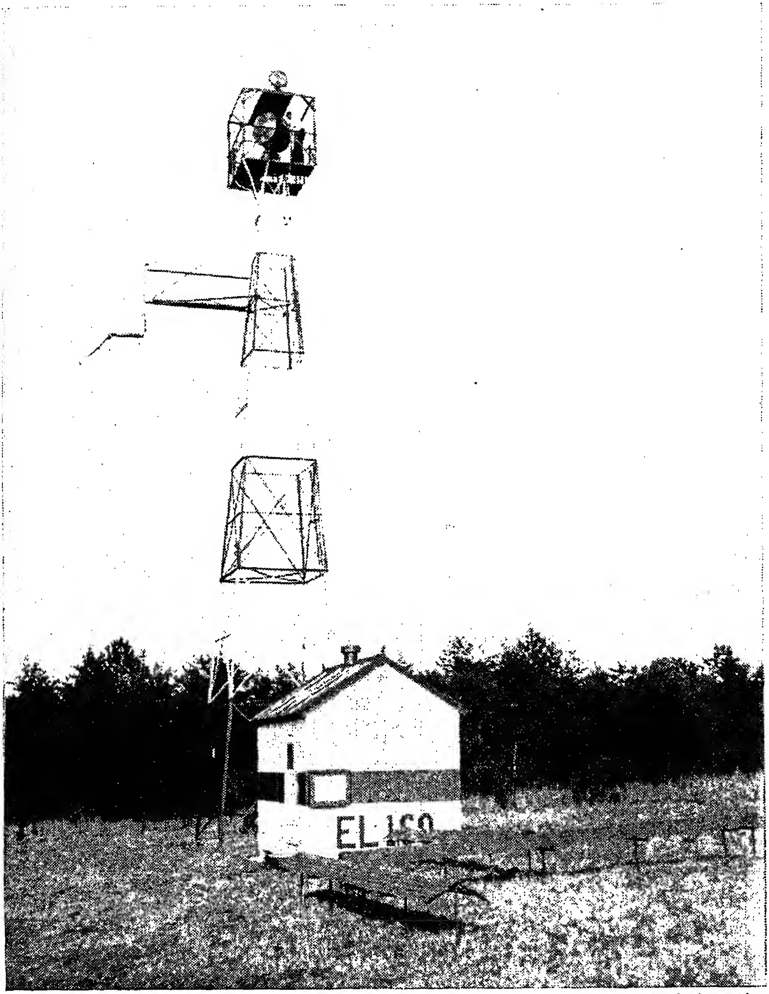
INTERMEDIATE AND AUXILIARY LANDING FIELDS ARE LOCATED ABOUT FIFTY MILES APART ALONG THE AIRWAYS

Avigation might be nothing more than watching for landmarks if planes flew only by day and in clear weather. Night extinguishes most landmarks and alters the appearance of others. Many natural landmarks cannot be seen at all. Rivers, lakes, and reservoirs may be seen if the moon is shining. So may railroad tracks and bridges. The lights of cities serve as guides. But the usual landmarks at night are insufficient for safe flying. Special night landmarks are, therefore, set up for planes. These are, of course, the beacons and the illuminated landing fields.

Beacons are of several types. Many of them rotate, so their

light is visible from all directions. Some beacons are also equipped with radio signals as further aids. The beacon is a 24-inch floodlight so equipped that a spare bulb goes into service when the regular one burns out. The light from the beacon is sent out at several degrees above the horizon, mostly at a low angle. The revolving light, making six circuits a minute, appears to the oncoming pilot as six flashes of light. These may be visible thirty or forty miles from the beacon. Beacons are spaced ten to fifteen miles apart along the civil airways depending on the power of the light. Lights vary from 2½ to 10 million candlepower. Besides the beacon light, each tower is provided with two 14-inch course lights. These send out an automatic dot-dash signal that identifies the beacon. The beacon at a regular landing field has green course lights. At an emergency field the lights are amber. All other course lights are red. Intermediate landing fields are spaced about fifty miles apart on main air routes. These are lighted at night with a distinctive pattern. The fields are marked with boundary lights to indicate the runway. There may also be obstruction lights, wind cone lights, hangar and field lights.

These are the kinds of landmarks on which the pilot depends. Contact flying (flying by means of visible landmarks) is the simplest and easiest way to fly. For some types of planes, when conditions permit, this is the only method used. There are important limitations to contact flying. Weather conditions may blot out even the most conspicuous landmarks and, since there is no control over the weather, the pilot who depends only on



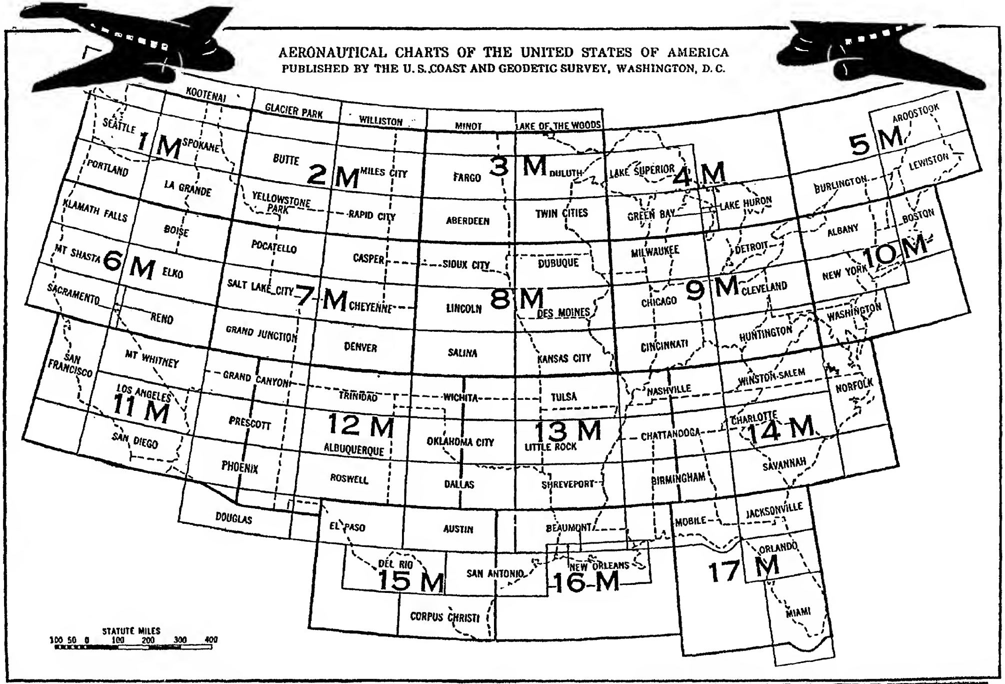
Courtesy of Civil Aeronautics Administration

POWERFUL BEACONS GUIDE PLANES AT NIGHT.
NOTICE THE MAN ADJUSTING THE LIGHT

visible landmarks must remain grounded during periods of low visibility or risk death in a crackup. Even in clear weather, going by visible landmarks is not always possible. Planes cover long distances rapidly and it would take years of training for a pilot to memorize all the landmarks that he might meet in flying in the United States alone. Airline pilots take a year or more before they are completely familiar with the landmarks along their own route.

Because it is nearly impossible for a person to have first-hand acquaintance with an untold number of railroads, towns, beacons, and mountains, pilots depend largely on maps and charts to locate and identify landmarks for them. A map has the job of describing, with symbols and abbreviations, the country over which a plane is traveling. The same story written out in words, page after page, would be useless to the pilot who must determine position rapidly. A map tells the story quickly—sometimes at a glance. But it is necessary to know how to read a map. Map reading takes study and skill. Every good pilot has been trained to read a map just as you once had to learn to read words.

Every word, line, color, and symbol on a map tells part of the story. It is necessary to understand clearly what each means before a map can be understood. Maps show natural features—mountains, valleys, lakes, glaciers, etc.—and show their size, shape, dimensions, and altitude. Maps also show cultural features—those produced by man: railroads, cities, power lines, etc. Besides these, maps show direction, distance, slope, and



Courtesy of U. S. Coast and Geodetic Survey

SECTIONAL AERONAUTICAL CHARTS AND REGIONAL CHARTS (NUMBERED) ARE BASIC GUIDES FOR THE NAVIGATOR

many other characteristics of land and water. Of these you will read in more detail later.

The U. S. Coast and Geodetic Survey has prepared a series of regional aeronautical charts covering seventeen regions of the United States. Each region is divided into three or more sections and for each section a large scale map is published. A total of eighty-seven sectional charts is available. With these basic maps supplemented by maps for use with radio compass, the pilot can easily plot courses and follow them. These charts are the basis of navigation. Whatever other instruments the pilot may use, he will come back to the charts to check his position and from them determine his future course. A pilot who cannot use maps is limited to local flying. If he really wants to use his wings, he has to learn how to use a map first.

The difference between a map and a chart is a minor one that you may ignore if you wish. Generally, a map refers to an area that is largely land. A chart is usually a map of ocean areas. However, the U. S. Coast and Geodetic Survey which has for many years produced nautical charts now makes maps for aviation use also. These are called aeronautical charts. They are the sectional, regional, and radio direction finding charts just mentioned.

Just as the use of visible landmarks alone has its limitations, so has the use of maps and charts. Unless you know direction, a chart may be difficult to use. If you do not know at least your approximate position, a chart may only be a vague sort of guide. As you can probably guess by now, each instrument and

method of navigation supplements the others and all together help make flying practical under every condition. In most cases it is necessary to supplement maps with instruments that will aid the pilot in determining his direction and position. There are a great many devices to help the pilot do this.

The instrument board of a modern stratoliner contains over a hundred dials, instruments, indicators, and controls. Of these only a few are direct avigation aids. The rest tell the pilot the condition of the plane and engines and permit him to appraise situations instantly and act quickly. For contact flying the Civil Air Regulations require that a plane carry an air speed indicator, altimeter, and a compass. A bank and turn indicator, clock, and climb indicator must be added if the plane does instrument flying, and the altimeter must be of a more sensitive type. Airliners also carry an artificial horizon, a directional gyro, and a second altimeter. These are minimum requirements and usually additional instrument aids are used.

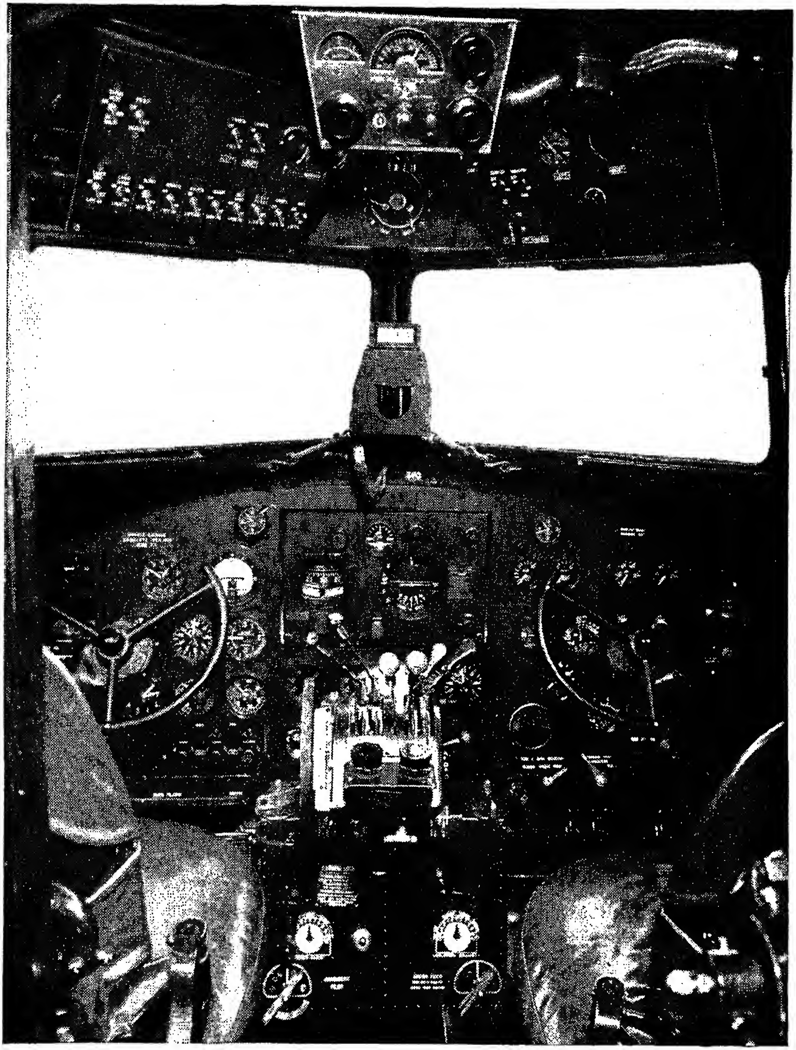
Some authorities suggest a minimum of five avigation instruments, including an accurate clock, a compass, an altimeter, an air speed indicator, and a drift indicator. Of course, a good pilot can navigate with less, but these instruments are essential aids of proved value. Some of these instruments may seem new and strange at first, but before you have finished this book you will feel as if you have always known them.

To determine his position the pilot may use a chronometer (navigation clock) because time differences are equivalent to differences of longitude. Every pilot knows that differences be-

tween Greenwich and local time are quickly translated into distances east or west of the prime meridian. A difference of fifteen degrees or one hour in time is exactly the same. Knowing elapsed time and speed of plane, the pilot can easily calculate distance covered.

The sextant, in one of its several forms, may be used to measure the height of the sun or some other heavenly body above the horizon. From such measurements latitude is determined. Since air travel is three dimensional, the pilot uses an altimeter, a sensitive form of barometer, to indicate his height above sea level. A large plane may also be equipped with a radio altimeter (also known as an absolute altimeter or terrain clearance indicator) that measures, by radio beams, the exact height of the plane above ground. This may be quite different from the height indicated by the altimeter which is affected by temperature and barometric changes. The radio direction finder is used in determining the position of the plane. You will find out more about these devices later.

The position of a plane in the air changes constantly. So in addition to knowing his position, the pilot needs to know how his position is changing. The air speed indicator tells him his forward speed. (A speedometer gives the same data to a car driver.) A climb indicator tells the pilot the rate at which the plane is ascending or falling. The gyro-horizon shows a departure from horizontal flight. The drift indicator tells if winds are blowing the plane off its course. These, and other radio instruments, tell the pilot how his position changes.



Courtesy of Transcontinental and Western Air, Inc.

THESE INSTRUMENTS IN THE COCKPIT OF A DOUGLAS DC-3 ARE FOR BOTH CONTROL AND NAVIGATION

Other instruments show direction or help keep the ship on a given course. There are several forms of the compass used in aircraft. The magnetic compass must be specially modified for avigation to give satisfactory results. The directional gyro is an important adjunct to the magnetic compass. The gyro quickly indicates any change of direction and is important in keeping the plane flying straight. The turn indicator is another gyroscopic device enabling the pilot to estimate and execute his turns with safety. The ultimate gyroscopic machine is the "third pilot," the automatic gyro-pilot that can take over control of the plane and hold it on a predetermined course.

The radio aids to navigation may be put into a separate group though they also determine position, direction, and speed. Radio is the keystone to instrument flying. With the use of proper instruments a pilot can now land safely in a pea soup fog. With a radio compass he can head directly for home. With a direction finder he can check and determine his position and direction. Through radio he can keep tabs on the radio beacons and radio direction stations so that, even if lost, the pilot can quickly find himself. Radio is an aid in landing, both for blind flying and, at more crowded airports, where traffic control is essential to safety. Radio brings the pilot the latest weather reports and enables him to foresee changes in atmospheric conditions.

Radio is becoming increasingly important in plane navigation. Some authorities claim that the day is not far distant when all a pilot will have to do is bring his plane within range of a

radio-operated airport and then relax. The landing of the plane will be accomplished automatically by radio beams.

There are a number of other minor aids to navigation, from the wind-sock flying above the hangar at the airport to parachute flares that may be used for emergency landing. Several types of signaling devices are useful in emergencies or if something goes wrong with the radio.

All of these, from the beacon light to the drift indicator, are tools for the pilot to use in getting his plane safely to its destination. Avigation involves the accurate use of these aids, together with a knowledge of the earth and air so that wise decisions can be quickly made, using the facts determined from maps and instruments. This knowledge of the earth is essential in flying—the shape, movements, and forces of the earth have determined once and for all the basis of avigation.

WE NAVIGATE THE EARTH

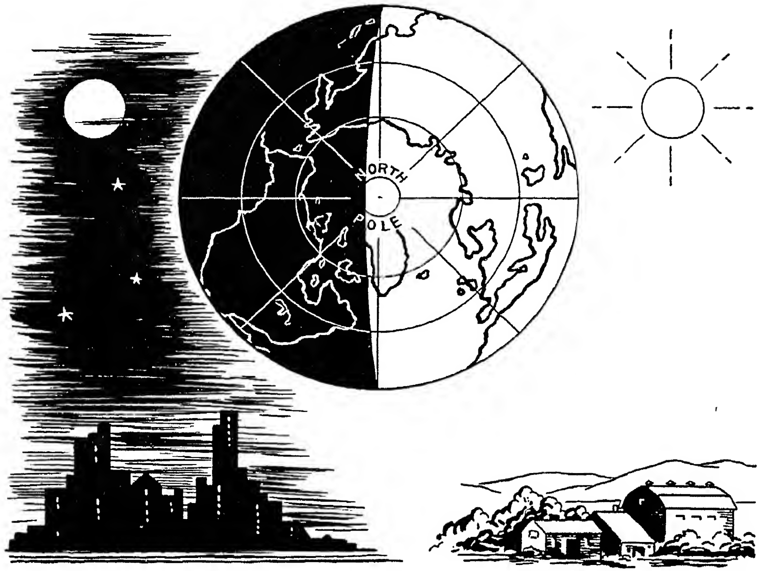
SOMETIME in the future, when rocket ships have been perfected, pilots will be concerned with the problems of inter-planetary travel. They will have to consider high velocities and gravitational fields so they will be sure to land on Mars or Venus. Meanwhile avigation is confined to the thin layer of air that surrounds the earth. It is to this earth and this atmosphere that we must now give our attention.

The mountains, oceans, and atmosphere of the earth that so greatly affect avigation have not always been as they are now. Each has a long and involved history extending millions of years into the past. Ever since the earth formed from material cast off from the sun it has been undergoing gradual changes, producing the physical features we see today. The continents and oceans have changed many times in evolving to their present form. Mountains have been built up and worn down. These great changes required tremendous energy. The energy that changed the earth in the past and is still changing it comes from our sun. The gasoline that drives a plane through the air and the winds that speed the plane on its way are both forms of solar energy.

Interesting as it may be, it is not necessary to trace the history of the earth from the very beginning in order to understand flying. We should be more attentive to the results of these past changes than to their causes. First, the results of this ancient activity have produced a spherical earth. If the earth were as flat as the best scientists of the Middle Ages firmly believed, then the mathematics of avigation would be within the scope of anyone who finished sixth grade. But the earth is round—not perfectly round, but almost so—and that makes a world of difference.

The diameter of a perfect sphere is the same in every direction. On the earth the diameter from pole to pole is 7,900 miles. Through the equator it is 7,927 miles. This slight flattening at the poles is not significant. A difference of approximately 30 miles in 8,000 is a matter of less than ½ of 1%. A craftsman turning out a ball of wood or metal by hand would consider himself good to achieve ½ of 1% accuracy. So for all practical purposes we can treat the earth as a sphere. All distances and directions mentioned in this book are measured on the surface of a spherical globe.

Our second heritage from the past is a moving earth, an earth that has been spinning on its axis and traveling around its parent sun for millions and millions of years. Because of this west to east spinning (once every 24 hours) the earth has the phenomena of day and night. Each town and village on the surface of the earth is spun away from the sun, and as evening comes the solid earth prevents the sunlight from reaching it. As morn-



THE ROTATION OF THE EARTH, PRODUCING NIGHT AND DAY, CREATES MANY AVIGATION PROBLEMS

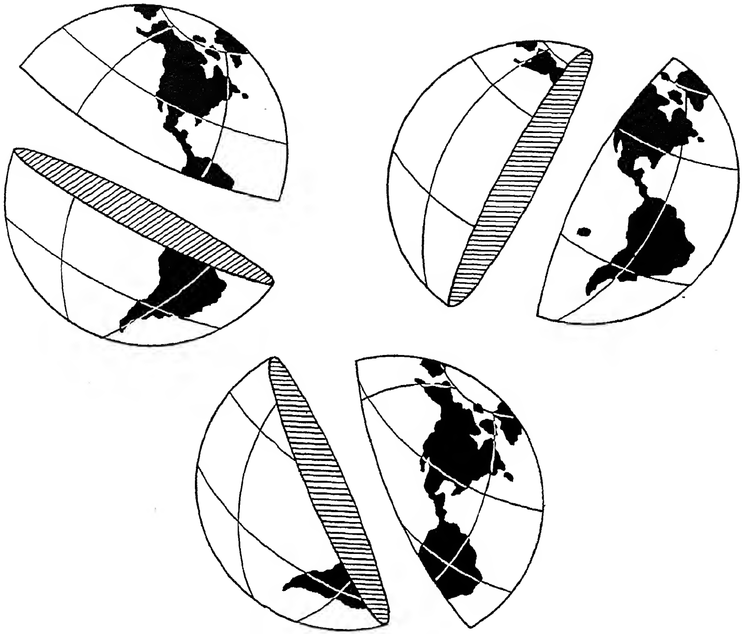
ing approaches, those parts of the earth in darkness spin into view of the sun again and there is light. Because we still use words that are a hangover from the Middle Ages, we speak of the sun and the stars as rising and setting, even though we know the real motion is that of the earth.

This spinning of the earth produces a whole set of navigation problems. Navigation at night is, as everyone knows, more difficult. The earth movements affect weather, especially the winds. But this same spinning makes it possible to observe apparent movements of heavenly bodies and reckon time.

The movement of the earth around the sun is much slower. The earth spins on its axis close to 365¼ times for every trip it makes around the sun. The path of the earth around the sun is almost a circle. We are about 3% nearer the sun in winter than in summer. This fact has nothing to do with the seasons. But the axis of the earth is tilted. The warming rays of the sun strike the earth at different angles as the earth moves around its orbit. When the angle of the sun is high its rays are more concentrated and the land is warmed. When the sun is low its heating effect is much less. Thus seasons are produced. Climate is affected and this in turn determines where people live and what they do —including where and when they fly.

The shape and movements of the earth have made it possible for scientists to set up accurate lines of reference that are the basis for our measurements. Avigation, as a science constantly using measurement, makes continual use of these lines of reference. Most of them are already familiar to you, but to repeat them now may emphasize their importance. First, there is the axis of the earth, an imaginary line or axle that is the shortest diameter of the earth. It extends through the two points of the earth where the daily spinning motion is reduced to zero—the geographic North and South Poles.

The axis is an imaginary line that goes through the earth. All the rest are lines on the surface. You may think of them as the edges of thin sheets or planes going through the earth. The equator might be used as an example. A plane extending at right angles to the axis, exactly halfway between the poles, forms a



ANY CIRCLE WHOSE PLANE DIVIDES THE EARTH IN HALF IS CALLED A GREAT CIRCLE. ALL THREE OF THESE ARE GREAT CIRCLES

circle where it touches the surface of the earth. This circle is the equator. If you measure on the surface of the earth, the equator will be equidistant from both poles. Furthermore, the plane of the equator extending through the center of the earth divides the earth into two equal parts. When the plane of any circle does this, the circle is called a *great circle*.

As the earth is a sphere, any number of circles may be drawn

on its surface. Let us draw enough so that they will serve as guide lines in locating cities and other places. We can begin by drawing circles around the earth, north and south of the equator, and all parallel to the equator. These circles have the axis of the earth going through their center (but only the equator has the center of the earth as its center). As we draw these lines farther and farther north and south the circles become smaller, and, nearing the poles, these parallel circles decrease till at the poles they disappear. These lines are *parallels of latitude.*

It has been the custom since Babylonian times to divide the circumference of circles into 360 equal parts known as degrees. The size of the circle does not matter. Each can be divided into 360 degrees. Picture a circle on the earth, starting at the equator, going through the North Pole then down to the equator again, to the South Pole, and ending at the equator. Beginning at the equator we can divide this circle into degrees. A quarter of the way around we will be at the North Pole. That will be the 90 degree mark. Back at the equator it will be 180 degrees; then 270 degrees at the South Pole, and finally 360 degrees back at the equator.

Now if we draw one of the parallels of latitude 1 degree north of the equator, the circle will go around the earth through the 179 degree mark on the other side and return. A parallel 45 degrees north of the equator will pass through the 135 degree point on the opposite side. If we draw parallels of latitude at 1 degree intervals, 90 of them will reach the pole going north and another 90 will reach the pole going south. Practically,

these circles north and south of the equator will enable us to locate earth features as far as distance from the equator is concerned. Latitude is measured in degrees up to 90 degrees north and 90 degrees south. These latitude circles constitute the north-south lines of reference on the earth.

It does not make much difference where we begin to draw east-west circles. Any number of circles can be drawn around the earth passing through the North and South Poles—each of these circles will divide the earth in half—making them great circles like the equator. Again we fall back on custom and take the great circle going through both poles and the little suburb of London, called Greenwich, as the starting point. We can now divide the equator up into 360 degrees and draw these longitudinal circles 1 degree apart. Each circle will pass through the poles and at every other point on the earth will be 1 degree apart. These are circles of longitude, and with them we can measure east and west directions.

You will quickly see that circles (or *meridians*) of longitude are very different from parallels of latitude. Meridians are all the same size. They are all great circles and they all meet at the poles. Each parallel of latitude is a different size. Only one (the equator) is a great circle and the parallels never meet. It is, therefore, impractical to measure longitude in the same way as latitude. Longitude is measured in degrees east and west of the Greenwich Meridian up to 180 degrees. Going both east and west for 180 degrees closes the complete circle of 360 degrees.

With these two series of circles, the parallels and the meridians, we have divided the surface of the earth into a kind of spherical checkerboard. Each division is not the same size, as the meridians narrow down toward the poles. This flaw cannot be helped. No other system would fit the surface of a sphere as well. At any rate we can locate cities, mountains, and lakes by these lines of reference and fit each into the checkerboard square. If this is not accurate enough, finer divisions may be created.

Each degree (written as the degree sign °) is divided into 60 minutes (symbol—′) and each minute into 60 seconds (symbol—″). These minutes and seconds are divisions of distance on a circle, or measures of an arc. They have the same names as the divisions of time, and degrees, minutes, and seconds of *longitude* can be changed into hours, minutes, and seconds of time.

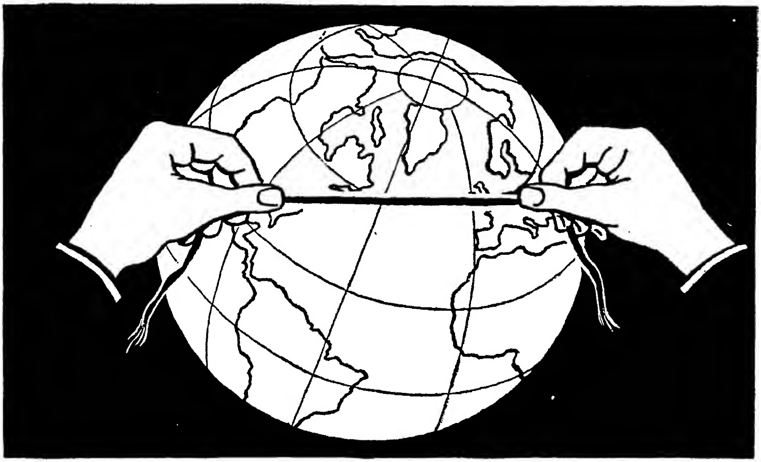
A circle may be divided into 360°, equaling 21,600′ or 1,296,000″. Each degree of latitude or a degree measured on any great circle is close to 69 miles. A minute of latitude or great circle measure is 6,080 feet (1 nautical mile) and a second is 100 feet. Thus a landmark surveyed down to the nearest minute could be easily located from a plane. It would be within an area approximately one mile square, an accurate enough location for an airport.

With this system any place on the surface of the earth may be accurately located. When the famous "Time Capsule" was buried at the New York World's Fair in 1940, to preserve a

record of our civilization for future generations, the site was accurately surveyed and the latitude and longitude measured. The time capsule is located at latitude 40° 44′ 34.089″ N. and longitude 73° 50′ 43.842″ W. These measurements are recorded in many libraries and universities and even thousands of years hence the capsule can be located within 50 feet by these two series of reference numbers.

An experienced avigator can measure latitude and longitude readily and can thus determine his position. He uses these reference lines in plotting any longer course. Every aeronautical chart makes use of these same reference lines.

The equator and all meridians are great circles. The planes of these circles divide the earth in half, which is another way of saying that the center of the circles and the center of the earth coincide. It is possible to draw more great circles besides the meridians and the equator. Great circles may be at any angle and may go in any direction, as long as they divide the earth in half. If you read any of the stories of famous aviation flights, of round-the-world trips, and of record-breaking flights you will frequently see the phrase "great circle route." For long distance flying the pilot will prefer to fly along a great circle. The pilot knows that just as sure as a straight line is the shortest distance between two points *on a flat surface*, a great circle is the shortest distance between two points *on a sphere*. If you want to find the shortest route between any two points on the earth get a globe (not a map) and stretch a string tightly between these points. The string will give you the shortest route



A STRING STRETCHED TIGHTLY BETWEEN ANY TWO POINTS ON A GLOBE IS PART OF A GREAT CIRCLE AND THE SHORTEST DISTANCE BETWEEN THOSE POINTS

and this route will be part of a great circle.

With parallels, meridians, and other great circles any point on the earth can be located and the shortest route to it determined. But there is more than this to avigation. The earth is nearly perfectly round and it is nearly perfectly smooth also. The highest mountains (6 miles) represent less than $\frac{1}{10}$ of 1% difference in the diameter of the earth. These are only tiny imperfections on a relatively smooth surface. But all planes fly in a thin sheet of atmosphere only four miles thick. In terms of the paths of planes, mountains become important barriers. Deserts, swamps, oceans, glaciers, and other uninhabited areas

may also be barriers to travel. The very shape and distribution of the continental masses and oceans dictate the routes of global avigation.

Recently, proposals for new air routes have been made. These are routes over the cold arctic regions. There is good reason behind the suggestion that polar air routes be developed. A piece of string and a globe will enable you to see for yourself how important polar routes between Europe and America might be. On the other side are the dangers of cold and storm. Many factors enter into the planning of air routes. The shortest distance is not necessarily the best.

These factors involving natural barriers, prevailing winds, fuel supplies, and many other problems make the difference between theoretical and practical avigation. Some of these factors are the natural features of the earth; some are people, their needs and demands. After all, planes and air routes are built to serve us. The purpose of flying is not just to get the plane any place—but to get it to a destination, a destination determined by the things people do and want.

All avigation is on a spherical earth and must be planned and executed in terms of this peculiar spinning ball on which we live. In order to get from place to place on this ball, planes must travel over land and water in a thin sheet of atmosphere that lies on the surface. While this atmosphere extends out to perhaps 600 miles, half the air lies within three miles of the earth's surface, and for practical purposes flying at heights above five or six miles is, so far, of limited value. This atmos-

Courtesy of Transcontinental and Western Air, Inc.

WHATEVER INSTRUMENTS THE NAVIGATOR MAY USE, HE ALWAYS REFERS BACK TO HIS AERONAUTICAL CHARTS

phere through which planes travel is no smooth road. The heat of the sun keeps it in constant motion and produces conditions within the air that may make flying impossible. As we learn the tricks of traveling through this changing atmosphere we fly with more certainty.

To keep your feet on the ground in dealing with avigation always bear in mind that the ground on which you are standing is part of a spherical earth and that air travel is always on a

route over the surface of a sphere in a line that is often some part of a circle. This simple fact will be of real help in dealing with maps and charts, which are a basic part of navigation equipment. The earth is a three-dimensional sphere. Maps are two-dimensional flat pieces of paper. Therein lies a source of confusion for many would-be pilots.

4

THE STORY MAPS TELL

EVERY map of the world is a compromise. It is never completely true and is always false to a degree. The fault is not with the map makers but with the earth itself. Because the earth is a sphere it cannot be truly and completely represented on a flat surface. This can only be done with small sections of the earth. In maps of a city, the curvature of the earth is unimportant. Mapping larger areas and the whole earth presents an unescapable difficulty because of the curvature of the earth's surface.

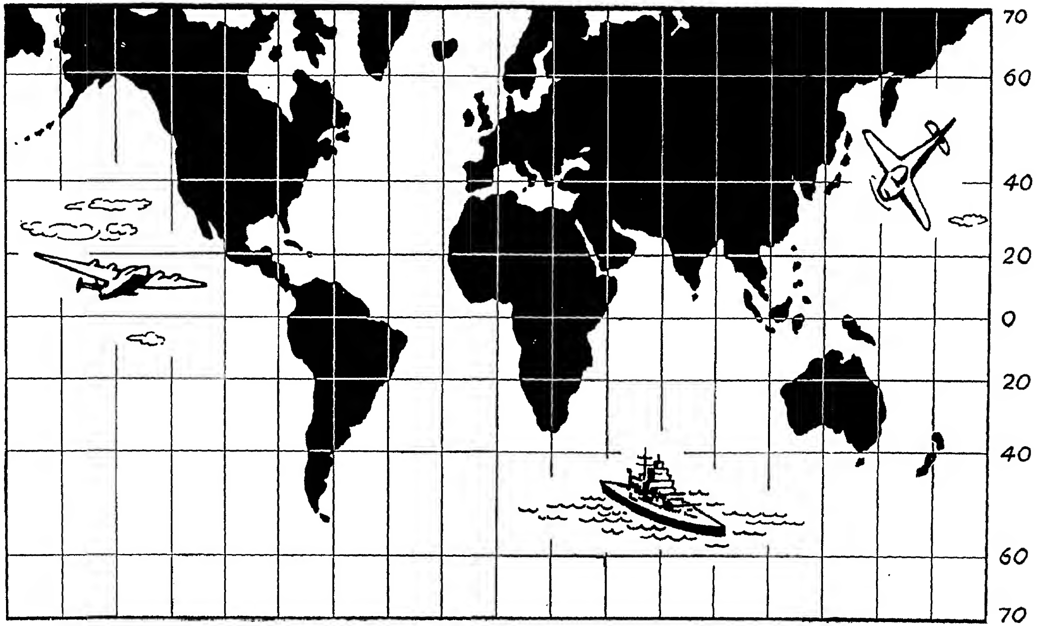
You can demonstrate this difficulty for yourself if you peel an orange carefully and then try to arrange the peels so they will form an even rectangle. Or you can reverse the process and take a sheet of paper large enough to fit around a globe or an orange and see if you can bend or fold it so that it will lie evenly over the spherical surface. A mathematician could clearly demonstrate why the surface of a sphere can only be approximated on a sheet of paper, but, I am afraid, his proof would only complicate the story. The difficulty is real and there is no solution to it except a compromise.

If the world were not a sphere but a cylinder, then merely unrolling the cylinder would present the surface as a flat sheet.

Map making would be simple. Mercator, the famed geographer (his real name was Gerhard Kremer), did exactly this in 1568. Mercator transferred or projected the surface of the spherical earth on to a cylinder and used this as the basis of his maps. Mercator's projection is still a widely used method of map making. Most naval charts and maps for general use follow his scheme.

But the fact remains that the earth is a sphere and not a cylinder. You can wind a cylinder of paper around a globe and see for yourself. At the equator the cylinder and the globe touch, but the walls of the cylinder go off at a tangent. As you go north or south the cylinder lies farther and farther from the globe. Parallels of latitude can be extended from the globe to the cylinder and still retain their correct position, but meridians of longitude which meet at the poles on the spherical earth appear as parallel lines on the cylinder and do not meet at all.

A Mercator map has this peculiar form. Parallels and meridians are straight lines at right angles. The meridians never meet, so the entire north edge of the map represents the point that should be the North Pole. Mercator found it practical to make the parallels proportionately wider apart near the poles because the meridians were wider than they should be. This forms a rectangle of surface area more closely approximating the conditions on earth. A Mercator map is most accurate near the equator and then distortion increases rapidly, making shapes appear unduly large at the polar regions. Mercator maps make Greenland with an area of 800,000 square miles look as large



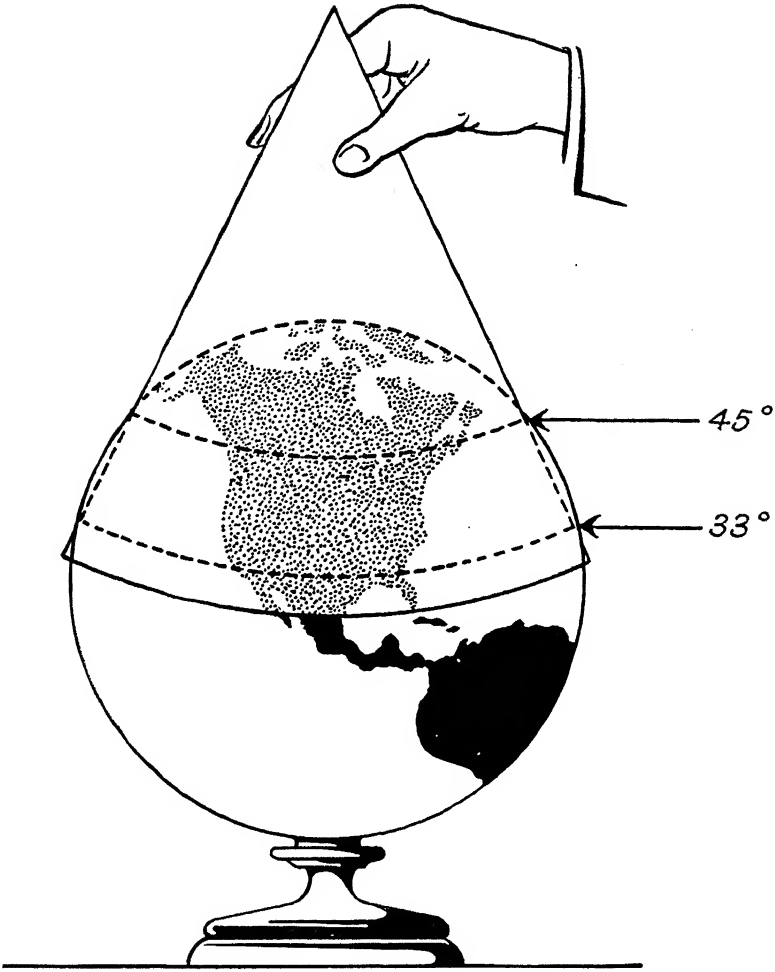
THE MERCATOR PROJECTION DISTORTS THE NORTH AND SOUTH EXTREMES OF THE EARTH

as South America with an area of nine times the size.

Briefly, a Mercator map does not give a true picture of the world. Yet Mercator maps are satisfactory for many purposes including navigation on board ship. Since the speed of ships is not great, a mathematical formula is used to correct the distortion of a Mercator map. Then the map may be used to plot the ship's course. The Mercator projection has certain distinct advantages. Since both parallels and meridians are straight lines, one type of course plotted on a Mercator chart appears as a straight line and crosses each meridian at the same angle. Such a course is easy to navigate.

There are a number of other projections used in making maps. Each has its particular advantages and certain disadvantages. Each is a compromise. Some projections show distances and direction more accurately and such types are of greater value for air navigation.

In 1772 Johann Lambert introduced a new form of projection which he later modified in several ways. Mercator fitted a cylinder to the spherical earth. Lambert twisted his paper into the form of a cone and stuck the mouth of the cone over the globe. You can try this yourself and you will see that the sides of the paper cone fit closer to the surface of the sphere than does the cylinder. If you discard the tip of the cone that extends far beyond the pole you have a form that fits the earth fairly well. Again the polar regions do not touch the globe but a good part of the distance from the equator to the poles does. This Lambert conical projection is therefore quite accurate for



THE LAMBERT PROJECTION IS BASED ON A CONE FITTED OVER THE EARTH. IT IS HIGHLY ACCURATE WITHIN A BELT 12 DEGREES WIDE

a belt of the earth about 25° wide. The same type of cone can also be used in the southern hemisphere.

This is an oversimplification of the Lambert projection, but it gives you the basic idea and you are welcome to pursue the details in more advanced books. Actually, the cone of the Lambert projection does not fit over the earth but intersects the surface at two points as shown in the diagram. The Lambert projection used in all aeronautical maps is designed so that it is exactly accurate at two parallels—33° and 45° N. Lat. At points north or south small distortions begin to appear. The error at any point over a range of 25° is scarcely more than 2%. For most of the United States the error is less than ½ of 1%. By the use of a different set of standard parallels, the Lambert conical projection can be made more accurate for regions farther north or south. This is equivalent to fitting a smaller- or larger-sized cone on the globe. For Alaska the standard parallels used are 55° and 65°. In this way the central portion of a map can be made the most accurate part.

On the Lambert projection the meridians are straight lines that converge at a point far off the map—actually at the tip of the cone. The parallels of latitude are shown as concentric circles. The meridians cross the parallels at right angles as on the Mercator projection. This helps in using the map. The Lambert type map has one other advantage. A straight line drawn on the map is approximately part of a great circle, and for that reason a straight line generally shows the shortest distance between two points. This is very different from the

Mercator projection where a straight line on the map is *not* the shortest distance. Only on long east-west distances does a straight line on the Lambert projection differ much from a great circle section. There are many practical reasons for adapting the Lambert projection for aerial maps. The U. S. Coast and Geodetic Survey has done so.

Map makers have devised a number of other projections offering specific advantages at the price of making still other distortions. One projection will emphasize the land masses and show them in their true proportions. Another will do the same for the oceans. A gnomic projection shows great circles as exact straight lines and hence is used in plotting long distance courses where a great circle route is preferred. There are several modifications of Lambert's projection. These are generally known as polyconic projections.

Mercator and Lambert projections are most widely used and you should try to recognize each. When plotting a course on a map the type of projection must be known. A course is plotted at a definite angle to the meridians. The same course, plotted in different projections, may appear completely changed.

The scale of a map is also important. Scale tells you the relationship in size between the map and the earth. The map is minutely smaller than the part of the earth it pictures. How much smaller is a critical question. The scale on a Lambert map is practically constant, so that an inch at the top of the map represents the same distance that it does at any other part.

On a Mercator projection the scale increases as you go north.

The distortion makes northern regions look proportionately larger than they really are. It increases about 50% from southern United States to Canada. The constant scale of the Lambert projection is a real advantage. Distances and areas may be more readily compared.

Scales differ with the uses of maps. A map of valuable city property might be made to a scale of 1 inch to 10 feet. Such a scale might be written 1 : 120 or as the fraction $\frac{1}{120}$. This means that one unit on the map (an inch, for example) equals 120 units (inches) on the earth—120 inches being, of course, 10 feet. Such a scale would be ridiculous for aviation use. The regional air maps of the United States are made on a scale of 1 inch equals 1,000,000 inches, 1 : 1,000,000, or 1 inch equals close to 16 miles. The more detailed sectional maps are on the scale of 1 : 500,000 or 1 inch to about 8 miles.

Maps for aviation have scales generally between 1 : 500,000 and 1 : 5,000,000 or roughly from 1 inch equals 8 miles to 1 inch equals 80 miles. The small scale maps are useful in planning extended flights. The larger scales are suited to normal piloting.

The speed and range of the plane often determine the most suitable maps for use in it. The pilot of a slow plane doing local travel may be adequately served by a few sectional maps. This would not do for the pilot of a speedy transcontinental plane. He streaks across the area covered by a sectional map in about an hour and a half. He travels largely with the aid of instruments and radio guides, so the airline pilot constantly uses the

radio direction finding charts (D-F charts) with a scale of 1 : 2,000,000 or 1 inch equals about 32 miles.

Of course on smaller scaled maps much detail must be omitted. But then the pilot of a fast transport does not continually look for detail. If it is necessary to have details in order to observe landmarks, he takes the large scale sectional maps from his bag. For contact flying, where the pilot goes from one landmark to the next, the sectional maps are essential. For instrument flying, where the pilot is going a relatively long distance on a plotted course, the regional or the D-F charts are used.

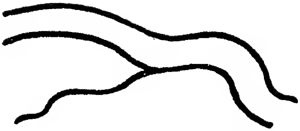
Even though maps are made to a definite scale, every feature on the map is not true to scale. Were this so, features important to the pilot, like beacons and railroad lines, would be too small to be seen. These important features are shown larger than the true scale just as road maps emphasize roads out of true proportion. Otherwise the scales are accurate and may be used to determine both size and distance.

The scales on maps are represented as a ratio or fraction that may be converted into any unit of distance such as feet or miles. Unfortunately there are two kinds of miles in use. Coast and Geodetic aeronautical charts are scaled in *statute* miles, which is the standard mile we all know—5,280 feet. The navy uses the *nautical* mile, which is a bit longer—6,080 feet. This nautical mile is the average length of one minute ($1/60°$) of latitude. Its use simplifies converting degree measure on the surface of the globe into distance measure when navigating.

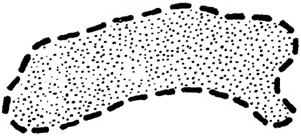
The scale of maps may also be given in kilometers—the measure of the metric system. A kilometer is $\frac{1}{10,000}$ the distance from the equator to the pole measured along any meridian—a distance equivalent to 3,280 feet or about $\frac{5}{8}$ of a statute mile. Unless the scale is marked otherwise, statute miles are used. Sometimes there are two scales, one in statute miles, the second in kilometers. It may help you to remember that 5 statute miles equal 8 kilometers and 66 nautical miles equal 76 statute miles.

The projection and scale are a sort of introduction to the map—a most important introduction, to be sure. Now you are ready to look more closely at the map itself. At first an aerial map is confusing because of the number of markings upon it. This is the time to take a good look at the portion of the Seattle sectional chart included at the end of this chapter. This is an actual part of a sectional chart that all pilots use. The chart may seem complicated but it really is not. Actually, there are only four groups of features, each shown by different colors and different conventional symbols. The symbols used on a map are good common sense marks for the things they represent. Once you know them they are easy to remember.

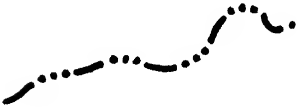
Water, relief, culture, and aeronautical data are the four things shown on these charts. On aeronautical charts and most other maps water features are shown in blue, small streams by a thin blue line and larger rivers by double blue lines with blue between. Lakes and oceans, of course, are blue also. In some sections of the country rivers and lakes dry up during



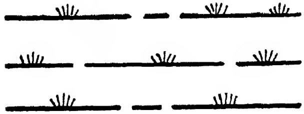
LARGE RIVER AND STREAM



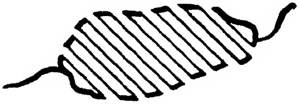
DRY LAKE



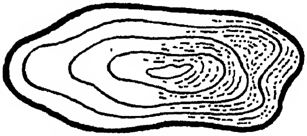
INTERMITTENT STREAM



MARSH



INTERMITTENT LAKE



GLACIER ON CONTOURED PEAK

ON AERONAUTICAL CHARTS BLUE SYMBOLS
REPRESENT WATER

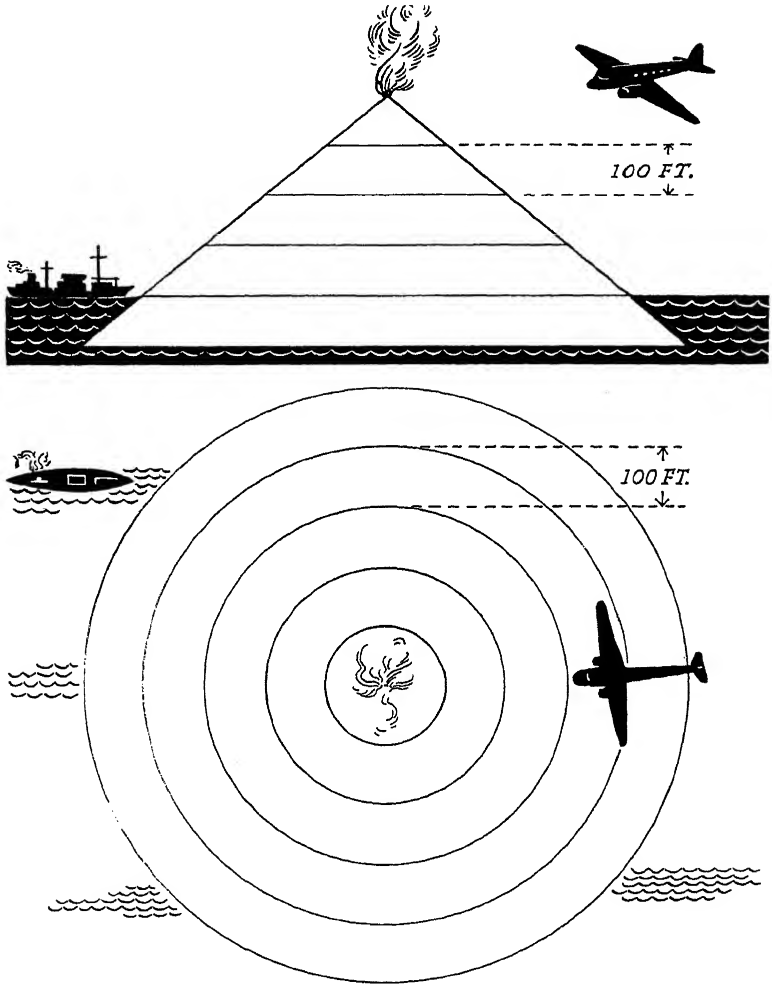
part of the year. Such intermittent streams and lakes are shown in blue dashed lines. There are a number of these streams in the northeast part of the Seattle chart. Marshes are marked by broken blue lines with small vertical dashes indicating clumps of marsh grasses. Blue may also represent ice as well as water. There are only a few glaciers in the United States, mostly in the mountains of the Northwest. You can see the symbol for glaciers all over Mt. Rainier.

Relief data refer to the uneven features of the land. Elevations and depressions are indicated on aerial maps. They are

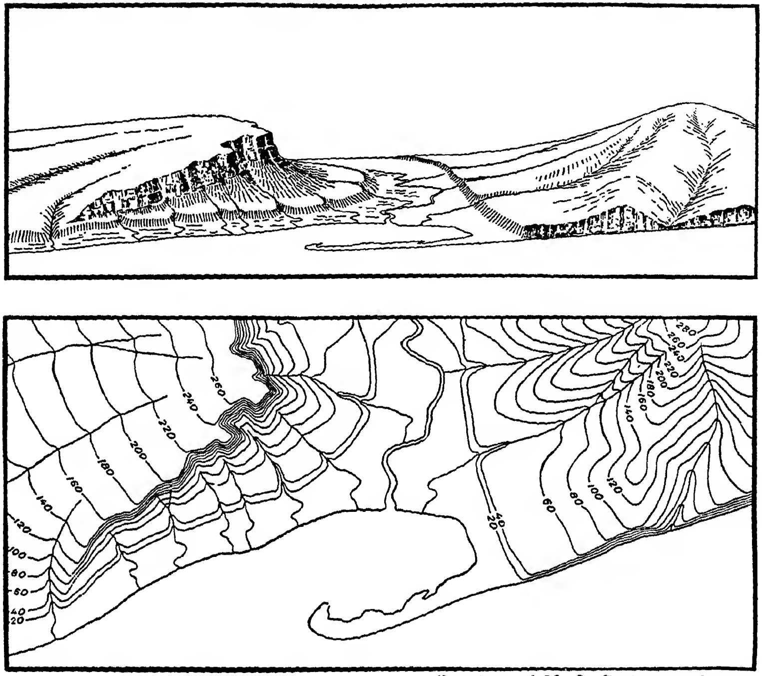
too important to be ignored. The basic way of showing elevation is by *contour lines.* These contour lines are lines connecting all points at the same elevation above sea level. The contour interval is often mentioned with the scale of the map. It may be 5, 20, 50, 100 or 1,000 feet. The 1,000 foot interval is used in sectional and regional maps.

Picture in your mind an imaginary volcanic island rising as a perfect cone out of the sea. A party of surveyors measures up the slope of the volcano till they are exactly 100 feet above the sea. There they drive a stake. They do this at many places and then connect all the stakes with a string. This string goes clear around the volcano forming a circle 100 feet above sea level. If we keep the surveyors on the job, repeating their task at 100 foot intervals, our volcano will soon be covered with a series of rings, each smaller than the last and each 100 feet above the other. From an airplane flying over the volcano the rings would appear as a series of concentric circles. One hundred foot contour lines are exactly the same thing, but the lines are imaginary. On a map showing relief by means of contour lines, the volcano would appear just as it would look from the plane—a series of concentric lines.

Contour lines are always the same *vertical* distance apart—but not horizontally. The distance between two contour lines always indicates the same change in elevation no matter how near or far apart the lines may be. On a cliff, where the ground rises abruptly, contour lines may be very close indicating a rapid vertical change and a small horizontal change. On sloping land



ROPES STRETCHED 100 FEET APART AROUND THIS IMAGINARY VOLCANIC ISLAND WOULD APPEAR AS CONCENTRIC CIRCLES FROM A PLANE FLYING OVER IT. CONTOUR LINES SHOW ELEVATION THE SAME WAY



Courtesy of U. S. Geological Survey

CONTOUR LINES SHOW ACCURATELY THE ELEVATION AND SHAPE OF LAND FORMS

the contours may be far apart showing the horizontal distances are in much greater proportion to the vertical. Contour lines not only show elevation but also show the slope or gradient, which is the relation between horizontal and vertical distance. With the use of contour lines and the scale it is easy to calculate how many feet the land rises or falls for a unit of horizontal distance.

The contours also indicate the shape of natural features as

the illustration shows. They tell many interesting details about the land if you can fully interpret their meaning.

Pilots must keep in mind that the highest contour does not show the highest land. If the highest contour line is the 5,000 foot contour, all points within that contour line are of an elevation between 5,000 and 6,000 feet. If any were over 6,000 there would be a 6,000 foot contour, but there may be many points 5,800 or 5,900 feet high that would not show on the map unless they were distinct peaks specially marked.

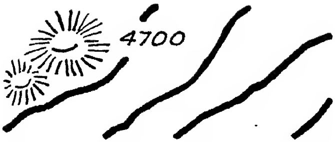
Relief is also indicated by color. All land forms are in green or brown. Often the interval between two contours is given a definite tint so that this elevation may be easily recognized. This is frequently done when the contour interval is large—1,000 feet or so. Then colors from green through different shades of brown indicate elevations from sea level up to 10,000 feet. Sharp peaks or cliffs are also shown by hachures or shading lines that make the point of land stand out. Peaks, distinct hills, passes, or divides are clearly marked with their exact elevation printed in black alongside the spot.

Pilots watch altitude and relief carefully. The character of the country often determines the condition of the air above it and consequently flying conditions. The pilot likes to know every possible place he can land in an emergency, so he studies his charts still more. The air regulations provide that he must fly at least 500 feet above the highest point on his route during the daytime and at least 1,000 feet above at night. The pilot must know the facts about relief as the altimeter in his plane

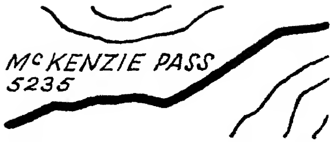
indicates height above sea level, not above the ground. The pilot makes sure from his chart that flying at a level he has chosen in advance will give him sufficient altitude to clear the highest points with a large margin of safety.

The most diversified group of symbols on the map is the group made up of cultural symbols—symbols that show the work of man. These are printed in black on aeronautical charts. There are a few exceptions. Large cities are in yellow, highways in purple, power lines and aviation structures in red. There are a large number of cultural symbols, some of which are especially useful to anyone trying to locate himself in the air. Race tracks, for example, are easy for a pilot to observe because of their oval shape.

Railroads are excellent landmarks from the air. They are shown by a heavy black line with a small vertical stroke at five mile intervals, symbols of a railroad tie. A double-tracked railroad is shown by a double tie mark. Tunnels are shown by a mark indicating entrance and exit with a double-dashed line between. Small towns are shown by a circle, larger ones by a square, and those of over 5,000 population are shown in their actual shape. Forest ranger stations are good landmarks in wild country. They are shown by a black house with a flag. A mine or quarry has the symbol of crossed picks. Any other distinctive landmark may be specially indicated. You will see all of these on the Seattle chart. Notice how the chart calls attention to conspicuous features—a power house, athletic field, race track, lumber mill or mine.



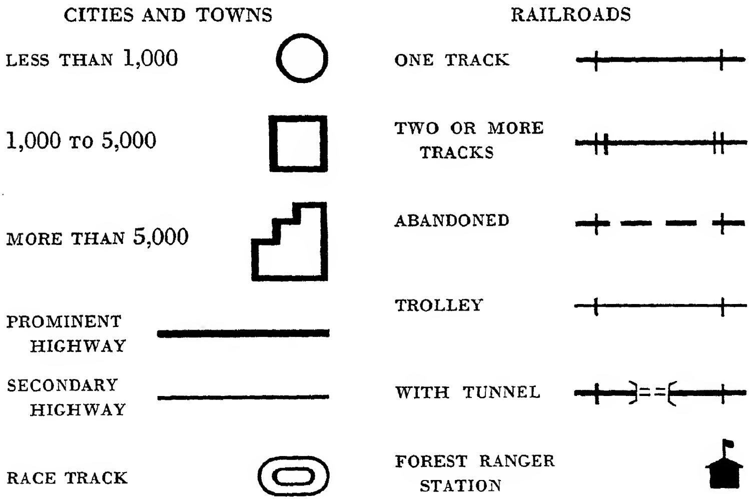
HACHURED PEAK WITH ELEVATION



MOUNTAIN PASS WITH ELEVATION

GRADIENT OF ELEVATIONS

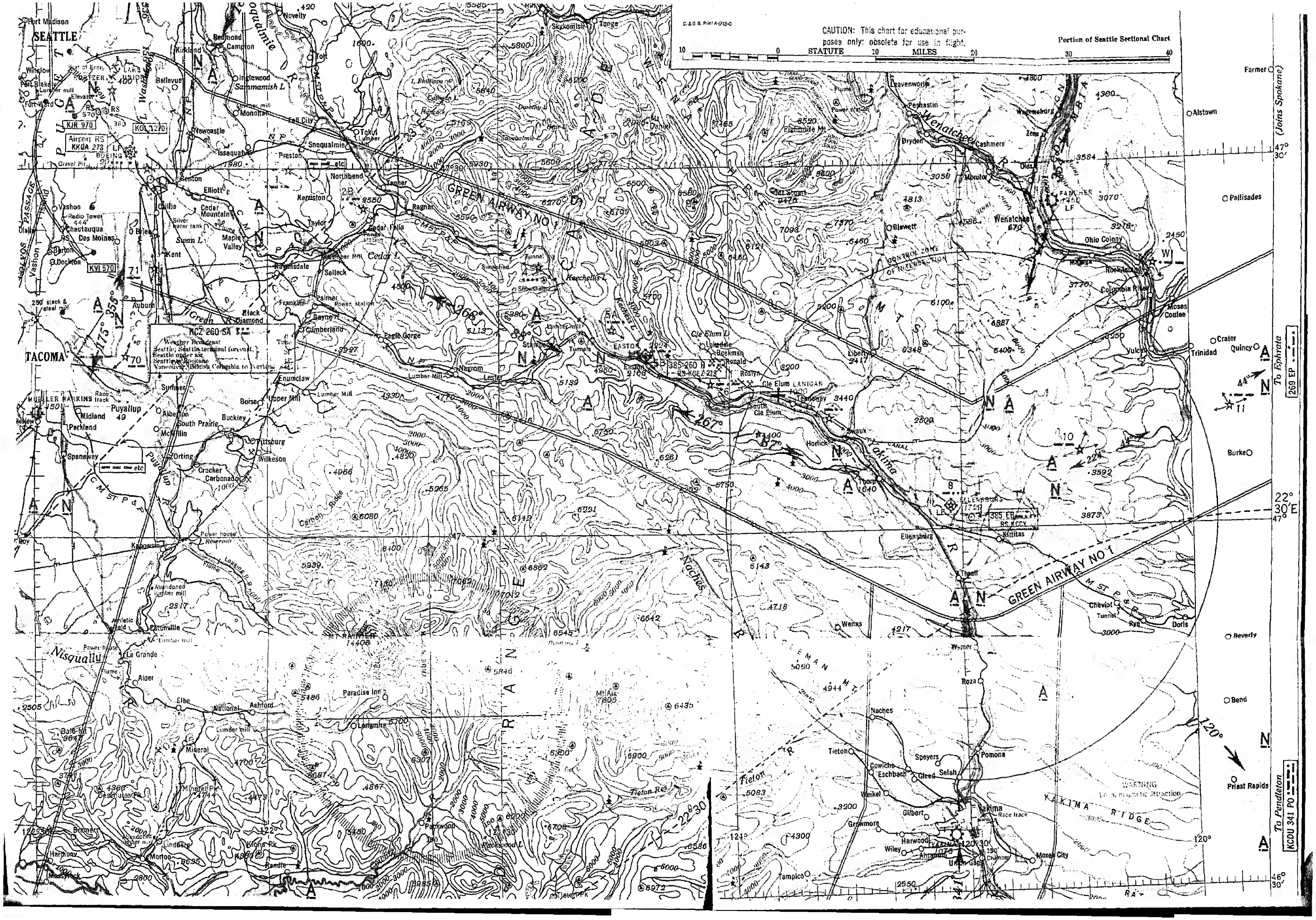
0–1000	1000–2000	2000–3000	3000–5000	5000–7000	7000–9000	9000–MAXIMUM
GREEN	LIGHT GREEN	PALE BROWN	LIGHT BROWN	MEDIUM BROWN	DEEP BROWN	DARK BROWN



ABOVE. RELIEF IS SHOWN BY CONTOUR LINES AND BY GRADATION OF COLOR

BELOW. MOST IMPORTANT ON THE PILOT'S CHARTS ARE THE SYMBOLS FOR CULTURE—THINGS THAT MAN HAS MADE

The last group of cultural symbols shown on the map are those directly pertaining to avigation. These symbols are printed in red and get first attention from the pilot. This group of symbols must be studied carefully, so we will use them to begin another chapter—a chapter to conclude the data about maps and charts.


CAUTION: This chart for educational purposes only: obsolete for use in flight.
Portion of Seattle Sectional Chart
STATUTE MILES
SEATTLE
TACOMA
GREEN AIRWAY NO 1
Wenatchee
Yakima
Ellensburg
Cle Elum
Snoqualmie
MT RAINIER 14408
Nisqually
Naches
Puyallup
To Ephrata
To Pendleton
(Joins Spokane)
YAKIMA RIDGE

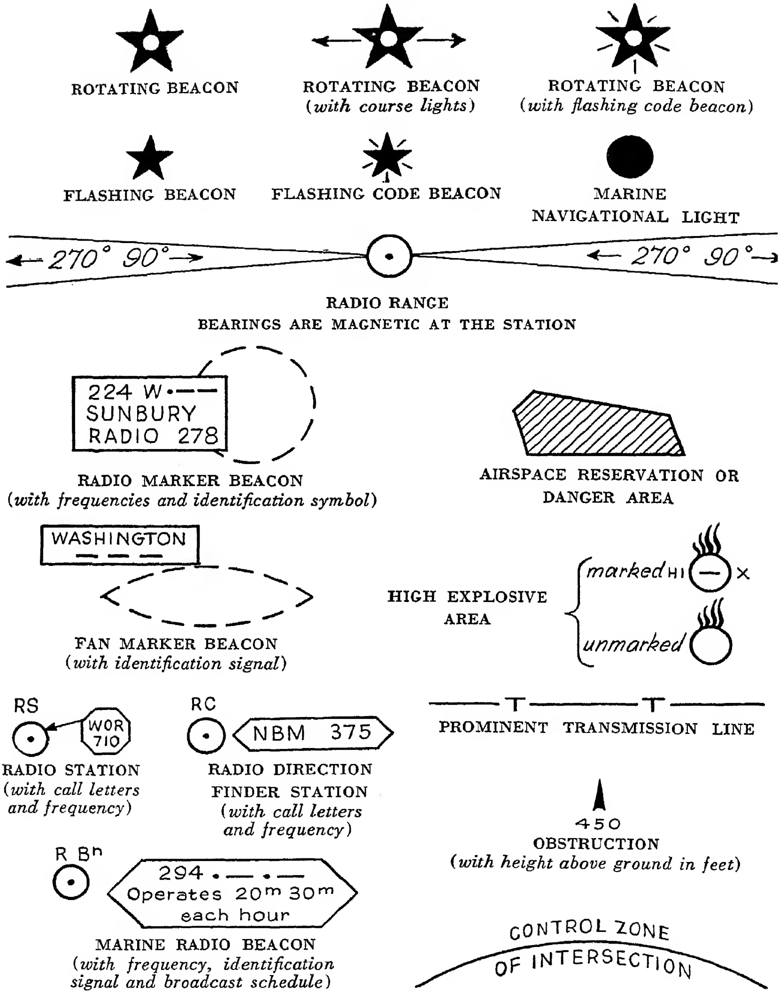
5

USING MAPS

THE INCLUSION of the aeronautical features makes air maps different from maps showing the same characters of relief and culture. The maps obviously emphasize the specific guides for the avigator. Airports are shown by prominent red circles. A double circle is a military airport. A circle with eight short spokes is a commercial or municipal airport. Civil Aeronautics Administration intermediate airports, intended largely for emergency use, are shown by circles with four short spokes. A seaplane base has an anchor inside the circle. A red cross marks an auxiliary flying field. The letters LF next to an airport mean "lighting facilities" and indicate that night landings are possible.

Beacons are indicated by a red star: a flashing beacon by a single star, a rotating beacon by a star with an open center. An arrow through the star is the symbol for course lights. Extra rays around the star mean that the beacon has a flashing code signal. You will find all of these on the portion of the Seattle sectional chart on which you have already seen the water, physical, and cultural symbols.

Radio aids to navigation are labeled to show the call letters, the frequency of the signal, and the identification of the signal



AERONAUTICAL SYMBOLS ARE SHOWN IN RED ON BOTH SECTIONAL AND REGIONAL CHARTS

itself. The radio range stations are shown as small red circles with a dot in the center of each. A pink tint marks the radio range to and from the station. The direction (magnetic) of the course is given in degrees. The letters A(· —) and N(— ·) mark signal areas used in finding direction when flying the radio range. Radio marker beacons are shown by a circle of broken lines. The size of the circle gives the range of the beacon. Another type of radio beacon is shown by an ellipse of broken lines. Data on radio weather forecasts and locations of commercial radio stations are also shown on the map, as you can easily see for yourself.

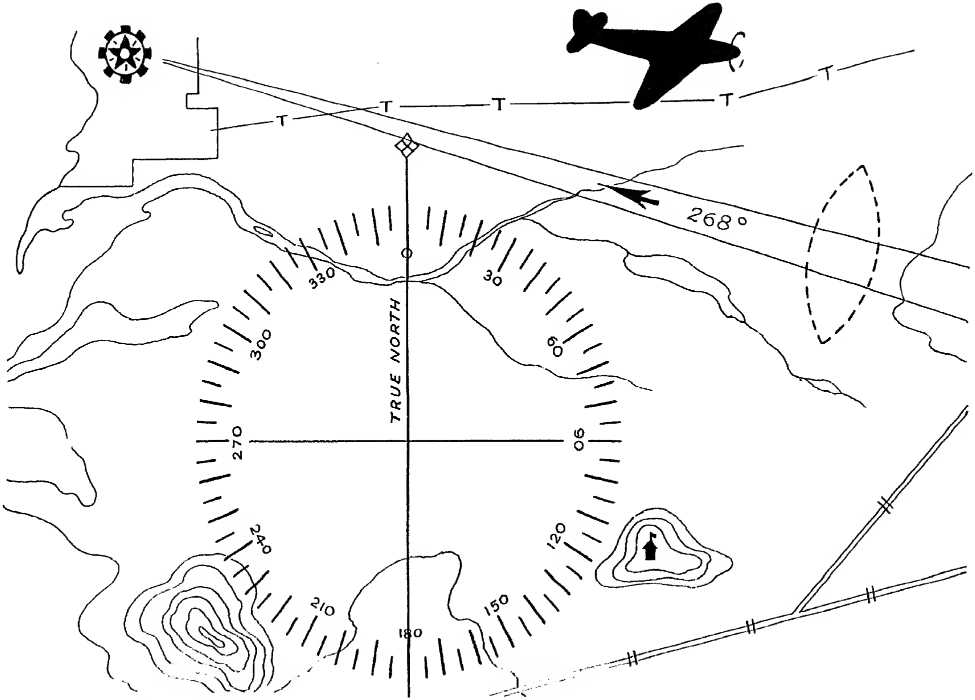
In addition to the radio symbols there are only a few others important for avigation. Certain areas are set off by the Army and Navy as prohibited areas over which civilians may not fly. Such an area appears on the edge of the Seattle chart just below Tacoma. These are shown by red boundaries filled by red cross-ruling. Isolated obstructions are marked by a tower with the height of the obstruction marked beneath. Also shown in red are heavy dashed lines usually curving across the map. These are lines along which the magnetic compass points one or more degrees east or west of true north. These lines are known as *isogonic lines*—lines of equal magnetic variation. They show lines of magnetic variation from true north in degrees. The line marking a variation of 23° E runs through the fan markers on the Seattle radio beam.

The circles marked in degrees on the aeronautical map are the compass roses. They show true north and are used to plot a

course. The readings on the compass rose and all reading of compass directions go *clockwise from north* so that east is 90°, south 180° and west 270°. This must be very clear so that numbers such as 45°, 315°, 265°, convey an instant idea of direction. The use of a pair of rulers always kept parallel to each other will permit you to measure direction anywhere on the chart by means of the compass rose.

Across the sectional and regional maps are belts twenty miles wide. Their boundaries are doubled red lines or solid red lines. These are the Civil Airways—the main air routes across the country. The Civil Airways are marked by the beacons, intermediate landing fields, and other aids previously mentioned. Air traffic is controlled within these belts, just as traffic lights and policemen control road traffic on highways. This traffic control reduces all chance of collision, especially in unfavorable weather, and enables both the pilot and the control stations to know exactly the location of each plane that is following the Civil Airways course. Distances and zones of intersection on the airways are shown on the charts.

The principal east-west airway is called the "Green Airway." The secondary east-west route is the "Red." The main north-south route is the "Orange Airway" and the secondary route is the "Blue." On these airways, west and southbound traffic travels at even thousands of feet—2,000, 4,000, 6,000, etc., and east and north traffic at odd thousands. At intersections, the "Green Airway" has the right of way. Planes flying this route maintain their altitude. Planes crossing the "Green Air-



THE COMPASS ROSE SHOWS THE PILOT TRUE NORTH ON HIS CHART

way" descend 500 feet for a distance of twenty miles as they cross.

These symbols, about which you have just read, are the alphabet of aeronautical charts. Without them the maps have no meaning. They must be learned before you can read and understand the maps. Like the isolated letters of the alphabet, the map symbols have little meaning alone. But when you can put them together and make the map tell you exactly what you want to know, then maps become as fascinating as blueprints are to an engineer.

A map is read like a book—but reading maps is not the same as reading a novel. A map is a guide book, best read before and while you are traveling so you can recognize and understand the things you see. Even experienced airline pilots keep their charts available for instant use every minute they are in the air. They have checked and rechecked their course so often they know the charts by heart.

If you could fly today you might take your map up in the air and compare the actual water, relief, culture, and direction with the symbols on the chart. If you are not ready to fly at this stage you can use the map as a substitute for air travel. The map will help you picture the actual terrain in your mind's eye. Using the Seattle chart, you can take a trip over glacier-covered Mt. Rainier or up the beautiful Yakima River. There is plenty to see in the Northwest even on an aeronautical chart.

Sectional maps may be purchased from the U. S. Coast and Geodetic Survey, Washington, D. C., except during wartime

when their distribution is restricted because of their value to the enemy. They are also sold by map dealers in a number of the larger cities. These sheets cost twenty-five cents. They are about 20 by 42 inches and cover an area of about 140 by 320 miles. If you can obtain the sectional map of the region around your home and study it carefully, you will really begin to see the story the map tells. If possible, check the map against places you know. Perhaps you will have to imagine how things look from the air. Use the contour lines and the relief symbols to see if you really get the picture of familiar mountains and valleys.

Air maps must be kept up to date. A map showing an airport no longer used or incorrect radio ranges may be a source of disaster. Maps are constantly checked and corrected. Corrections are made as soon as possible for important changes and every three or four years government experts fly over all areas shown on sectional maps and carefully check each feature from the air.

Because the air maps are continually revised, the Coast and Geodetic Survey often has on hand obsolete maps. These maps can no longer be used for actual navigation, but they are admirably suited for study. Teachers and students of aviation have been able in peacetime to secure these maps from the Coast and Geodetic Survey at Washington. The chart in this book has been altered by government experts. It is excellent to study but would be unsafe for a pilot to use in avigation.

There are a number of things to do with maps that will di-

rectly help you to understand them. The first step is to get some maps. The best are those sectional maps just mentioned. The topographic maps of the U. S. Geological Survey are also good. These maps are on a larger scale than the sectional maps, covering an area of about 13 by 16 miles, for those printed on a 1 : 62,500 scale (1 inch equals about 1 mile). They show water, relief, and culture but have no aeronautical symbols. These maps cost ten cents for each quadrangle and may be purchased directly from the Geological Survey at Washington. Key maps for each state are furnished free, showing what quadrangle covers your town or region.

You will find that even road maps are worth studying. They are the cheapest and easiest to get. Some are excellently made and show many of the physical features usually found on topographic maps. The scale will be different for each state but it generally runs between 1 inch to 10 miles and 1 inch to 30 miles. The scale approximates sectional and regional maps, and since road maps are free you can certainly start with them. Wherever and however you begin, become familiar with maps. Spend hour after hour with them until every last word and symbol has a meaning that you understand.

There are a number of specific things you can do with maps. Here are a few suggestions. Such things as plotting a course are yet to come, but meantime take a sectional or topographical map (or the Seattle sheet again). Just pick out some interesting point at random. Perhaps the top of Mt. Rainier or the town of Cle Elum on the Seattle section. Now determine as exactly as you

can the latitude and longitude of that spot. If you know how to interpolate figures in a table the same method applies to a map. If not, your job is merely to calculate the proportionate distance of your spot from the lines marking the nearest parallels and meridians. On the sectional maps, latitude and longitude are marked at 30′ intervals, or every half degree. If this 30′ of latitude occupies, let us say, 4 inches on your map and your dot is 2 inches from the parallel, you merely add $2/4$ of 30′ to the reading of the parallel to get the latitude of your dot. The fraction will not be so simple when you take the actual measurements, but with a little patience you can locate your spot to the nearest minute of latitude and longitude. You can pick a fair-sized city on your map, figure out the latitude and longitude, then check in an atlas to see if you are correct. Road maps do not show latitude or longitude, but with an atlas and map scale you can put in your own reference lines if you wish.

Your map will indicate direction by an arrow or a compass rose. Lay out the other directions. Make your own compass rose. Draw a circle about 4 inches in diameter. Put in the north-south line and then a perpendicular for east-west. Next work in lines at 10° intervals all around to 360°. East will be 90°, etc. Set this rose with the north-south line on any meridian of your map and you are ready to go. You can lay a ruler on your map and see what points lie on an east-west line. What would you hit if you went straight 60°? Because the meridians converge slightly on the Lambert projection, the compass rose only shows true north for the meridian on which it is located. Directions taken

from a compass rose more than 2° away will be somewhat in error.

It is important to learn how to estimate direction. Pick a city or some prominent spot on your map. Estimate, in degrees, the direction of some other city or place from it. When you have made your estimate set the compass rose on the nearest meridian and check. Do this over and over again till you can really estimate direction with a degree of accuracy. Every pilot finds such skill useful.

You can turn your attention to the relief on the map. Find the highest point of land and the lowest. Follow a river and see the curve of contour lines as the river crosses them. See if you can find a relationship between the relief and roads, towns, and railroads. You are likely to see that physical and cultural features develop in definite patterns and show interesting relationships which you could confirm if you made a careful study of the history of the region. Then use your imagination with the relief. Where would *you* run an airline?

Give the scale of your map some serious attention. Look at it carefully; then estimate the distance between any two cities on your map. How far do you figure it from Tacoma to Yakima? From Ellenburg to the Seattle airport? Get a ruler and check with the scale. You can write down your estimate, the measured distance, then figure out your percentage error. If you estimate 80 miles and this distance is 100, you are off 20 miles in 100 or have a 20% error. Do this ten, fifteen, or twenty times and see if your estimating improves till your percentage error falls

below 5%. If you can estimate distances and directions accurately, you have a knack that may be invaluable in an emergency.

Time and distance are equally good measurements. Something may be a mile away, or a fifteen minute walk. The next town is just about a half hour's drive—and you know that means about 15 miles. You can translate distances on your map into a time scale and hence estimate the time to travel by air from one point to another. In doing this you must assume that the air speed of your plane is the same as the ground speed and that there is no wind drift to affect your true speed. You'll find out how to make those corrections later.

Draw a vertical line 6 inches long near the left margin of a piece of heavy paper. Mark this off at 1 inch intervals. Then draw horizontal lines 1 inch apart from the vertical line to the right. Mark the top horizontal line 60 miles per hour, the next line 80, then 100, and so on down to 180 miles per hour on the last line. Now go back to the scale of your map. If it does not give an inch to mile scale, do a bit of arithmetic and figure it out for yourself. Let us suppose your map has a scale of 1 inch equals 8 miles, which is that of sectional charts. That means one mile is represented by 1/8 inch—a pretty small space.

Take the air speed of 60 miles per hour—this equals one mile per minute, or 1/8 inch on your map. Now 1/8 of an inch is too hard to measure and 1 minute is too short a time. So take a time interval of 4 minutes during which (at 60 miles per hour) you cover 4/8 or 1/2 inch on your map. Now measure out 1/2

inch on the 60 mile line and make a mark—above it write "4 minutes." Measure another half inch and mark it "8 minutes" and so forth out to an hour or more. Move down to the 120 mile per hour line and do the same thing. Here your speed is *twice* as great and in 4 minutes you will go twice the distance —or 1 inch on your map. So you mark the 120 mile line off in 1 inch intervals.

The rest is easy. Set your ruler on the 4 minute mark at both the 60 and 120 mile per hour lines and draw a line through both and extending right down to the end of the scale at the 180 mile line. Do the same with the 8 minute marks, 12 minute, etc. These vertical lines will all slant and the ones at the end may run off your paper. Don't let that bother you. When you have finished you have a time scale for your map for all air speeds from 60 miles per hour up to 180. Of course, you must use the actual scale of your map—not ⅛ inch equals 1 mile unless you are sticking to the sectional chart.

Using the scale is easy, too. You can, for example, find how far you could travel from your home in 40 minutes at the air speed of 100 miles per hour. All you do is take a compass, dividers, or ruler, set it on the time scale for the 100 mile per hour speed and measure to the 40 minute mark. Once you have the dividers set or have the measurement on your ruler, turn to your map again. You can easily measure and see.

You might reverse the problem. Pick two towns on your map and try to find out how long it would take you to go between them at a cruising speed of 140 miles per hour. Measure the

distance or set it on a divider. Then set the ruler or divider along the 140 mile line on the scale. Your measure may not strike a vertical minute line exactly but you can interpolate or estimate the fraction of the 4 minute interval and come out with an answer, accurate to the nearest minute, for the time of your theoretical trip. See for yourself how many ways you can use your time scale, but do not forget that you can only use the time scale with the correct map scale.

6

THE COMPASS

To call the compass the most useful of all avigation instruments might not be an exaggeration. But the compass is as imperfect as it is important. The pilot must pay as much attention to what the compass does not do as to what it does. The compass *does not* show north. The compass *does not* constantly point in the same direction. The compass *does not* accurately show a change of direction. In spite of all its variations and limitations the magnetic compass is still a basic instrument. Larger and more costly devices may take its place under special conditions but, in general, the pilot needs and uses his compass.

Any science text book will tell you how magnets work if you do not know already. Magnets attract iron and similar metals. When a second magnet is brought near, the two will either pull toward each other or will push away. Whether two magnets attract or repel depends on which poles have been brought in proximity. The two ends or poles of a magnet, while identical in appearance, act very differently. So differently that they are direct opposites. That is why one pole of a magnet is labeled the north pole and the other the south. These labels are

arbitrary and have nothing to do with direction. The terms north and south are in a sense confusing, so the north end of a magnet is sometimes called the blue end and the south end, the red.

No matter what you call the two opposite ends, they attract each other strongly. North attracts south, blue attracts red; unlike poles attract. The two like poles repel. North repels north, south repels south—blue pushes blue away and reds do likewise. This peculiar action of magnets is true for any magnet no matter what its size and shape. Of itself, it has nothing to do with the compass or direction.

The relation between magnets and compasses is elementary. To convert a bar or rod-shaped magnet into a compass all you do is tie a string about the center of the magnet and let it hang freely in the air. The same bar of iron that was called a magnet when lying on the table is called a compass when suspended, so it swings freely. You might arrange the bar so it pivots on a point and achieves the same results. So long as the bar is free to move, the magnet has become a compass.

The earth is a huge magnet probably because its deep interior is iron and similar metals. Like every other magnet the magnetic forces of the earth act as if concentrated at the two magnetic poles. The north magnetic pole of the earth is located in Canada, northwest of Hudson Bay (Lat. 73° N. Long. 96° W.) and the south magnetic pole is in South Victoria Land (Lat. 72° S. Long. 155° E.). The north and south magnetic poles are not very near the geographic poles that mark the north and

south ends of the earth's axis.

The actual compass used on planes is a considerable improvement over a swinging bar magnet, yet it is basically the same. The earth, like every other magnet, has a north or blue pole and a south or red pole. The earth is, of course, a large magnet, and while it may not be as powerful as the magnet with which you pick up nails, its weak but widespread magnetic force is felt all over. Every piece of iron and every magnet is influenced by the magnetic force of the earth. This force is too small to move a magnet lying on the table. But as soon as a magnet is suspended so that it can swing freely, friction is reduced, and the magnetic fields of the earth and the magnet affect one another. The swinging magnet is moved by these forces till the end of the magnet swings around toward the north magnetic pole of the earth toward which it is attracted. For convenience, the end of the compass that is attracted toward the north magnetic pole is called the north-seeking end or, briefly, the north end.

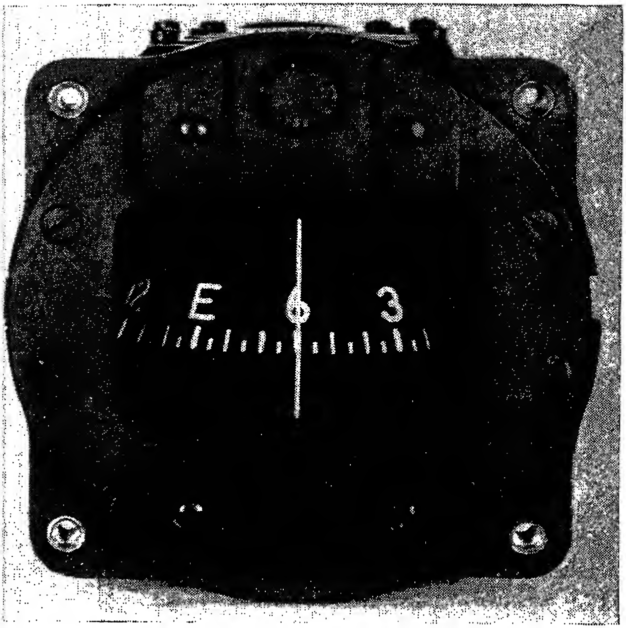
Just the opposite happens in the southern hemisphere, but the result is the same. The south-seeking or south pole of the swinging magnet (or compass) swings toward the south magnetic pole of the earth. The compass points to the magnetic pole no matter where on the earth the compass may be.

In the workings of the compass two magnets are involved. One large and fixed, the other small and movable. Keep in mind that the total energy of this interaction between the magnetic field of the earth and that of a small swinging magnet is minute. Any

resistance, motion, or vibration is likely to mask or nullify the magnetic attraction. No one could steer a plane using a compass as crude as that used by Columbus. The vibrations of the engines would throw the needle completely off. The electrical system of the plane would deflect it and the motion of the plane would cause the needle to swing wildly.

The magnetic compass on a plane is designed to meet the special conditions of avigation. Essentially it is the same as any other magnetic compass. Practically it is different. The compass is mounted on the instrument panel so the pilot sees only the edge of the instrument. Instead of a needle there is a moving compass card to which several magnetized needles are attached. This compass card is delicately balanced, so delicately that the vibrations of the plane and the shock of landing might throw the card off its pivot. To support the card and to reduce vibrations and shock, the compass card is suspended in a clear non-freezing solution of alcohol and water or other fluid. This liquid "dampens" oscillations of the compass and makes the movements of the card slower and steadier.

The plane compass is marked in reverse as a convenience to the pilot. The south edge of the card is marked north. Imagine yourself in the pilot's seat seeing only a small part of the revolving compass card and you will appreciate the idea of reversed markings. The card is marked at 5° intervals with a line and 10° intervals with a longer line. Every 30° the line is numbered—with the last zero omitted. Some larger compasses are marked in single degrees. On the glass front of the compass is a

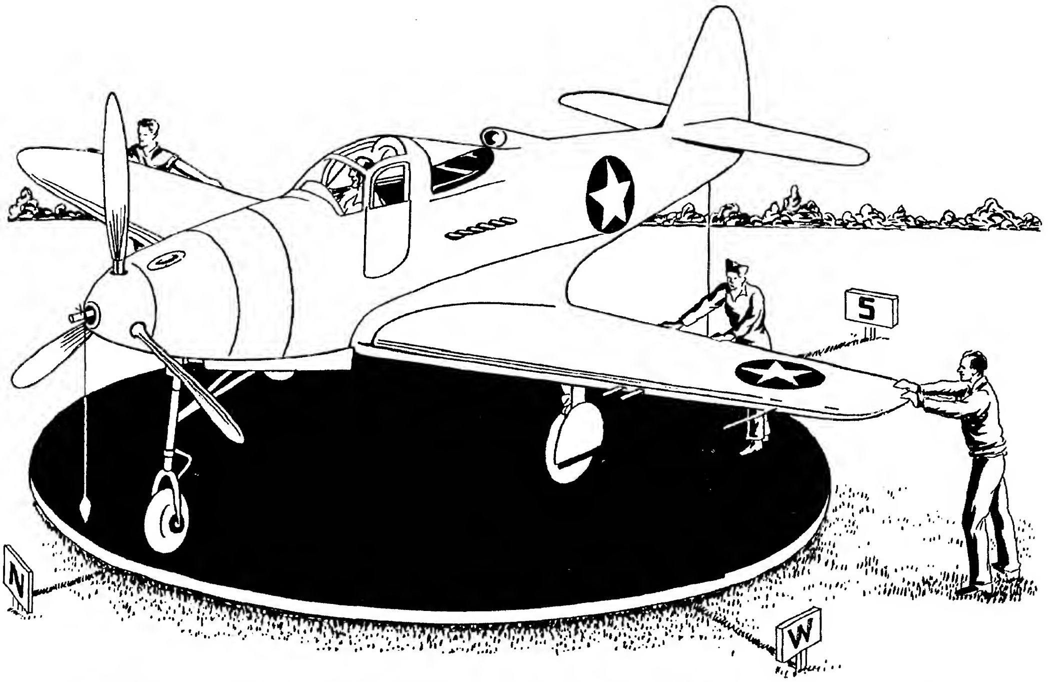


Courtesy of Pioneer Instrument, Division of Bendix Aviation Corporation

THE AVIGATOR'S COMPASS HAS A SWINGING DIAL WHICH MOVES PAST THE LUBBER LINE ON THE COMPASS FACE

straight vertical line known as the *lubber line*. When the compass is installed in the plane this line is set so it is on the fore and aft axis of the ship. Therefore the lubber line represents the direction in which the plane is traveling.

The compass in a plane is not ready for use until every factor in the plane that affects the compass has been tracked down. These factors that cause the compass to deviate from



THE PILOT CORRECTS HIS COMPASS FOR MAGNETIC DEVIATION BY SWINGING THE SHIP

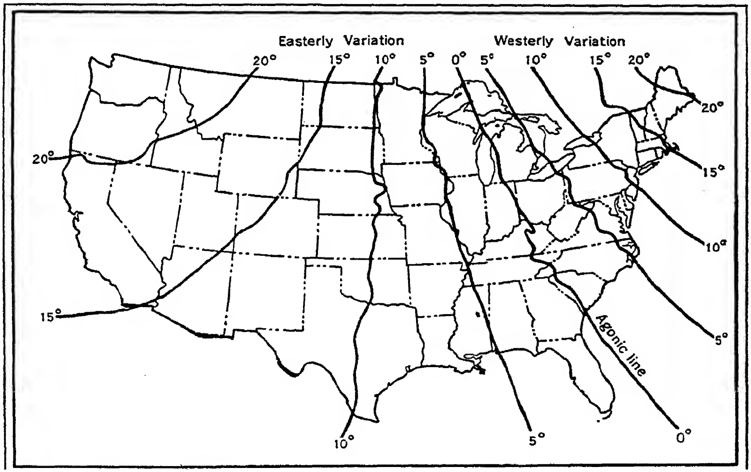
giving accurate magnetic directions differ from plane to plane and even differ as the plane flies in varying directions. They may be caused by electric circuits in the plane or iron parts near the compass. Errors due to these causes are called *magnetic deviation.* The compass is corrected for deviation with the plane under flying conditions and the motor running. Each compass has an adjustment screw for making the major corrections, or tubes in which small compensating magnets may be placed. Airfields often have a compass testing platform on which the plane can be swung around and the compass deviations worked out. This adjustment of the compass is known as "swinging the ship" and a lot of swinging must be done till the errors of the compass are fully known.

Some of the ship's swinging can be done in flight over courses of known direction. Major corrections are made within the compass but small errors of only a few degrees may persist. It is generally impossible to secure a perfect correction for deviation. Instead the pilot notes down the remaining deviation at 30° intervals around the compass card. When the job is finished, this information is summed up in a card showing the deviation of the compass from accurate magnetic direction. Such a card is kept in plain sight near the compass. The compass should be checked after every 150 hours of flight and after any repairs or changes in the plane.

After all this preparation, the compass is ready for use. Its use involves even more detail than the installation and compensation. You have to *learn* how to use a compass and, as with

everything in avigation, you can't count on a second chance too often.

The first thing you must learn and constantly remember is that a compass practically never points to true or geographic north. It points generally toward *magnetic* north. But as far as true direction goes it may be pointing north, south, east, or west depending only on the part of the world in which the compass is located. In a plane off Greenland the compass might be pointing to magnetic north but is actually pointing westward. In Alaska it points eastward and if the plane flew on over the



Courtesy of U. S. Geological Survey

ONLY ALONG THE AGONIC LINE DOES THE COMPASS POINT TO TRUE NORTH. AT ALL OTHER PLACES IN THE UNITED STATES IT POINTS SOMEWHAT EAST OR WEST OF NORTH

barren islands north of Canada in the Arctic, the compass would point south.

In the United States the only place the compass points true north is along a line that extends from the Bahama Islands through the Carolinas, Kentucky, and Indiana. This *agonic* line, as it is called, continues through Lake Michigan and Lake Superior northward toward the magnetic pole. On this line a magnetic compass points north. East of this line the compass points *west* of true north, and west of the line the compass points *east* of true north.

The difference is known as *magnetic variation* or declination. It is very distinct from deviation. Deviation is a result of local disturbance within the plane. Variation is due to a geographic condition—the fact that the magnetic poles of the earth are not at the same place as the geographic poles.

There is nothing to do about magnetic variation but accept it. In all computations involving the compass it is necessary to add or subtract the magnetic variation for the part of the country where the compass reading is being made. In the course of a trancontinental flight the variation may change from 12° W. to 18° E., a matter of 30°. The sectional and regional aeronautical charts are marked with lines (*isogonic lines*) showing the magnetic variation at 1° intervals. As long as the pilot knows his approximate position he can apply the necessary correction to convert magnetic direction to true direction. These corrections must be used even before the flight begins. When the course is plotted, the directions on the map must be converted

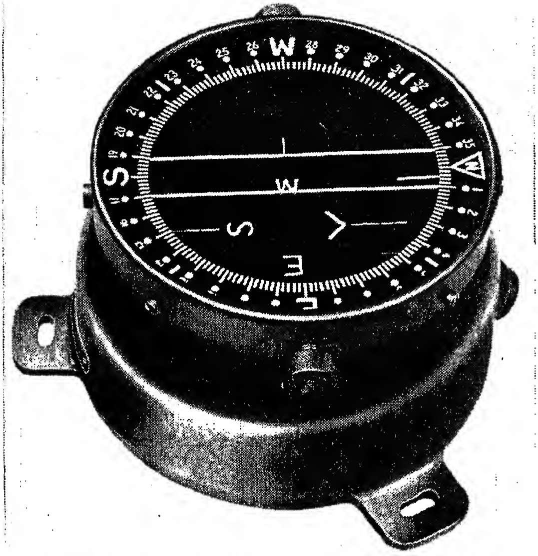
into magnetic directions so the pilot may steer directly by compass.

There are further complications to magnetic variation. It is not a constant error but a continually changing one. In some places changes from hour to hour may be noticed. Generally the changes are slower and amount to not more than three minutes ($\frac{1}{20}^\circ$) each year in any part of the United States. These changes make it necessary for the Coast and Geodetic Survey to recheck the isogonic lines every five years and to revise their charts of magnetic variation accordingly.

As a final complication to bother the navigator, there are still other forces that affect the magnetic compass. These are isolated spots of strong magnetic variation, sometimes due to local deposits of magnetic minerals, sometimes of unexplained origin. Then magnetic storms cause trouble. Some of these are local, others are felt all over the earth and are known to be related to the sunspots that periodically appear in increasing numbers on the surface of the sun.

It might seem that all the variations, deviations, and compensations would be just too much to bother about and that the compass should be retired. The facts, however, still show that the compass is a sound and basic guide to direction. The corrections necessary for its accurate use make the compass that much better and that much safer in avigation.

A magnetic compass is not an instrument of high accuracy. A pilot must be satisfied if he is actually within 3° or 5° of his course when flying by compass. The compass itself will not



Courtesy of Pioneer Instrument, Division of Bendix Aviation Corporation

THE APERIODIC COMPASS IS LEAST DISTURBED BY THE VIBRATIONS AND MOVEMENTS OF THE PLANE

yield greater accuracy any more than you can expect to measure hundredths of an inch using a ruler marked with sixteenths. Large transport planes sometimes carry another type of compass that is 3 to 5 times as accurate as the ordinary magnetic type. This *aperiodic* compass makes it possible for a pilot to hold his course within a degree or less, once compensations have been made. The aperiodic compass reduces the weight of moving parts to a minimum and otherwise eliminates oscillations. It cannot be mounted on the usual instrument board as the

pilot must see the whole compass face.

A newer and more improved compass is the *remote indicating compass.* This model is involved in its structure but is more free than other types from errors of deviation. This freedom from local effects is obtained by placing the compass at the tail of the plane or some other spot where experience shows electric and magnetic effects are at a minimum. A compass in such a position is not only freed from most deviation error but is quite inaccessible to the pilot.

There is no direct mechanical connection between this compass and the dial that the pilot watches. As the compass turns in its specially designed chamber, its rotating magnetic field produces a change in the field of a magnetized coil of wire mounted directly beneath the compass. The compass and the electrical pick-up system form the transmitting unit. This controls the current flowing in the coil and through the wires connecting to the compass indicator on the instrument panel. The changing current duplicates on the indicator dial any changes that the master compass makes. As many as three indicators can run from one compass and pick-up. The remote indicating compass has improved magnets and special design that gives it a still greater advantage.

Many planes also have a directional gyroscope to supplement the compass in showing direction. The directional gyro operates on the principle of inertia, a fundamental property of all objects that have weight. All objects at rest tend to remain at rest, and all objects in motion remain in motion because of

this property. It takes an outside force to alter the state of an object at rest or in motion.

In the directional gyro a small but heavy wheel is kept spinning by an air turbine. This high speed wheel continues to revolve in a fixed direction irrespective of the direction the plane is taking. In other words the direction of the plane may change but not the direction of the gyro. Attached to the framework of the gyro is a compass card marked in degrees. In front of it is a lubber line similar to the magnetic compass. The lubber line, of course, moves as the plane moves. The card remains fixed with the gyroscope. Thus direction is indicated.

The directional gyro may be set with the magnetic compass and will then show change of direction more quickly and more accurately than the compass will. The directional gyro does not maintain its set direction for long periods and is frequently reset with the compass. This makes it impossible to replace the compass with the directional gyro. But for actually holding a course, or for returning to the course after a sharp turn, the directional gyro is of definite assistance. When a pilot makes a sharp turn of, say, 150°, the movement of his compass may not keep up with the change of direction of the plane and hence it will be difficult to judge the completion of the turn by compass alone. The directional gyro responds faster and a more accurate turn results. The more elaborate instrument used on transport planes, the automatic gyro pilot, includes a directional gyro as an essential part of its mechanism. More about both these instruments later.

PLOTTING THE COURSE

If you could only arrange to move the magnetic pole up to the geographic pole and improve the compass so that it would not be affected by local magnetic fields, this chapter might easily be eliminated. The plotting of a course would then be simple.

Plotting a course is an essential procedure in avigation. Unlike the driver of a car, the pilot cannot stop in mid-air and decide which way to go. He must have the route carefully worked out in advance so that while flying he has only to check position and perhaps modify his route for weather changes or correction of avigation error.

Plotting a course is not necessary for a short air trip in very clear weather. The familiar landmarks around the airport and an occasional glance at the compass may be enough. But as soon as the distance and time in the air become considerable, flying a plotted course is not only good flying, but is a safeguard no pilot should be without. Flying the airways, especially with radio aids, makes the task much easier for the pilot. The course is predetermined by the airway route, but even so, the pilot must, before taking off, file a flight plan that contains data ordinarily

used in plotting a course. The detailed flight plans that the airlines require of their pilots include far more facts than the private flier need consider in making a flight.

This basic preparation for a trip involves the chart and compass. Since you are familiar with both, now is the time to use them. You can plot a course yourself. Only simple arithmetic and your present knowledge are involved. It is only fair to warn you that this simple arithmetic is tricky, even though it is only addition, subtraction, the use of map scales and compass. The pilot who adds when he should have subtracted may find his course is getting him far from his destination.

In plotting a course the pilot first decides which way he wants to go; then how to steer his plane to get there. If variation, deviation, and wind did not exist, the pilot would hold his plane on a 185° course—if that was the way he was headed. Because of the imperfect world and imperfect compass the pilot may head his plane almost every way but 185° in order to go in that direction. He may set his compass at 153° or 218° or some other computed direction. Let us follow the process with the pilot, from the decision of where to go to the important job of how to get there.

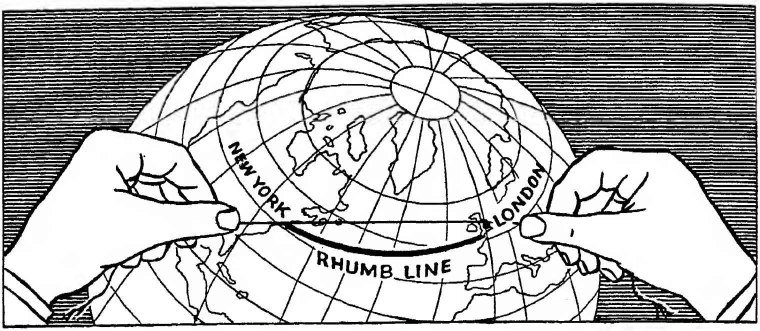
The pilot's destination will probably be an airport at some city. He must have a general idea as to its distance and direction. If not, he consults his chart immediately. If the distance is anything over 1,000 miles, the pilot will not go directly to the sectional charts. Laying out a course on half a dozen charts or more would be a nuisance. Instead, he uses the Coast and

Geodetic Survey Aeronautical Planning Chart that covers the United States on a scale of 1 : 5,000,000, or 1 inch to about 80 miles. This scale is $\frac{1}{10}$ that of the sectional maps. For somewhat shorter distances, regional maps are satisfactory. If he is using radio aids, the pilot may work directly on the radio D-F charts.

Once the destination is located, the true course may be plotted. This immediately brings us back to our projection. On the Lambert projection the meridians converge at an angle of .6° when one degree apart. If the direction of a course is measured on the meridian midway between the start and the destination the slight error due to the projection will be minimized. This is satisfactory if the course does not extend more than 4°. If the course is longer, the pilot must break it up into sections of not more than 3° or 4° and must measure his course on the middle meridian of each section.

In flying from Elkhart, Indiana (Long. 86° W.), to Bloomington, Illinois (Long. 89° W.), the pilot would measure his true course on neither the 86° or 89° meridian, but halfway between. This would be 87° 30′—the longitude of Chicago. If the course were longer—perhaps 20°, then it could be broken into five 4° sections and the course determined at the middle meridian of each.

In breaking a long course into sections, the pilot is actually transforming part of a great circle into a series of shorter straight lines. Each of these lines crosses the meridians at the same angle so this section of 3° or 4° may be flown as a definite



PILOTS MAY FLY A RHUMB LINE COURSE, WHICH CROSSES EACH MERIDIAN AT THE SAME ANGLE. THE RHUMB LINE COURSE FROM NEW YORK TO LONDON, SHOWN BY THE HEAVY BLACK LINE, IS 140 MILES LONGER THAN THE GREAT CIRCLE COURSE BUT IS EASIER TO NAVIGATE

compass course, once corrections for variation and deviation have been made. If this were not done, the pilot would have to change his course continually, as the angle at which great circles cross the meridians differs slightly from one meridian to the next. The lines crossing the meridians at a fixed angle are called *rhumb lines*. Following a rhumb line course is easier for the pilot than following a great circle course directly.

Pilots speak of direction in two ways. They speak of a *course* and a *bearing*. The course is the direction of a rhumb line. The bearing is the direction of a great circle. As you know, the course is measured on the halfway meridian. A bearing is measured through the meridian at the point where the measurement is made. As meridians converge on the Lambert projec-

tion, a bearing is constantly changing as the pilot progresses along his great circle route. Since the course is on a rhumb line that crosses each meridian at the same angle, it may be followed without change, though it is somewhat longer than the true great circle route. For example, the rhumb line course from New York to London is 140 miles longer than the great circle route between these two places.

The course that the avigator plots on his chart is known as the true course. The direction of the destination is measured from true geographic north. This is only the starting point. The true course must be transferred to a magnetic course, the magnetic course to a compass course, and finally, the compass course into a compass heading. This is not nearly as involved as it sounds. It only means that allowance must be made for variation, deviation, and wind. These corrections should not cause difficulty.

To obtain a magnetic course from the true course we come back to the fact that the magnetic and geographic poles are in different places. The magnetic course is oriented in terms of the magnetic pole instead of the geographic pole. You remember that in eastern United States the compass needle points west of true north and that in the rest of the country the variation is east. To obtain the magnetic course you simply have to remember to *add western variation* to the course and *subtract eastern variation.* You will find the variation given on sectional charts, on the planning charts, and on a special chart of magnetic variation published by the Coast and Geodetic Survey. The map on page 81 gives a rough idea of these variations.

If the course is long, the pilot must keep in mind that variation changes across the country. His safest procedure is to divide his course into short rhumb lines of 3° or 4° as previously mentioned; then correct with the average magnetic variation for each section of the route. This rough example of a course from New York City to St. Louis, Missouri, via Pittsburgh, broken down into eight sections, illustrates how the magnetic course is formed from the true course.

New York to St. Louis

	True Course	*Average Variation*	*Magnetic Course*
1st leg	274°	10° W. (add)	284°
2nd leg	273°	8° W. (add)	281°
3rd leg	253°	6° W. (add)	259°
4th leg	261°	4° W. (add)	265°
5th leg	265°	2° W. (add)	267°
6th leg	264°	no correction	264°
7th leg	254°	2° E. (subtract)	252°
8th leg	253°	4° E. (subtract)	249°

The magnetic course is just an intermediate step. No pilot flies directly on a magnetic course, though he constantly refers to it while in the air. If the compass in the plane were perfect, he might fly a magnetic course in still air, but in practice he must make further corrections for compass deviation and wind.

The pilot gets his compass deviations from the deviation card that was carefully made out when the compass was last checked. The deviation card may look something like the following:

DEVIATION CARD

Magnetic Course	*Deviation*	*Compass Course*
N. 0°	2° W.	2°
30°	3° W.	33°
60°	4° W.	64°
E. 90°	2° W.	92°
120°	1° W.	121°
150°	none	150°
S. 180°	1° E.	179°
210°	3° E.	207°
240°	4° E.	236°
W. 270°	2° E.	268°
300°	1° E.	299°
330°	none	330°

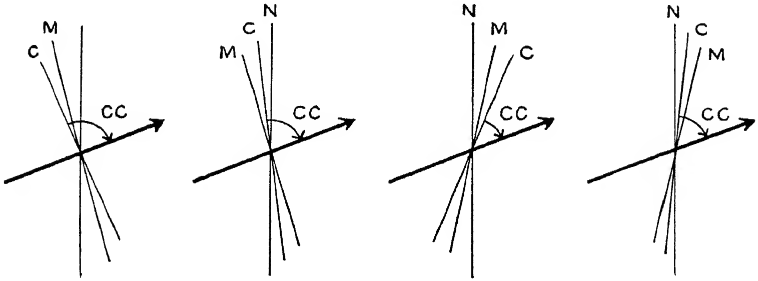
After the magnetic direction has been obtained from the true direction, the compass direction is obtained from the magnetic direction by the same method—*add western deviation* and *subtract eastern.*

The pilot's calculations to this stage involve two sets of corrections and his data might look as follows:

True Course	*Variation*	*Magnetic Course*	*Deviation*	*Compass Course*
240°	11° W. (add)	251°	4° E. (sub.)	247°
30°	6° W. (add)	36°	3° W. (add)	39°

In obtaining both the magnetic and compass course the arithmetic is simple. *Add* western variation and deviation because the compass points too far to the west and hence falls short of true north. Eastern variations and deviations are *subtracted* as the

compass points too far east and has overshot true north. The following diagram shows this graphically.



HERE ARE DIFFERENT COMBINATIONS OF DEVIATION AND VARIATION INVOLVED IN ESTABLISHING A COMPASS COURSE (SEE PAGE 99 FOR TERMS.)

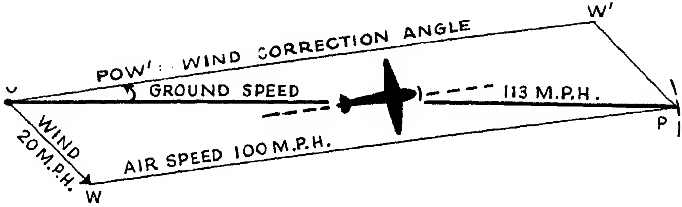
The last step in getting from paper to the air is to obtain a *compass heading*. Here is one last correction to add or subtract. It is determined by the direction and speed of the wind. The pilot always makes a clear distinction between his *compass course* and *compass heading*. The first is the true course corrected for deviation and variation. The compass heading is the same with the wind correction added. The pilot gets this wind information just before he takes off. He will probably get further revised data while he is flying. No experienced pilot underestimates this last step. The wind can undo all his calculations if he does not make adequate allowance for it.

Wind is nothing more than moving air—but practically the term refers to air in horizontal motion across the surface of the earth. Winds exist in great variety and you will find more facts

about them later. Meanwhile you need only be concerned with their speed and direction. The moving air carries planes along with it just as the current of a river carries driftwood. It makes no difference what the plane is doing, which way it is going or how fast. As long as it is in the air it is being carried with the wind with whatever direction and speed the air mass is moving.

The fact that every plane drifts with the wind makes it necessary to talk about two speeds of the plane. The *air speed* of the plane is its speed through the air as measured by an air speed indicator. This might be considered a theoretical speed as it is independent of the earth. Air speed is the equivalent of the speed of a swimmer in a river. The swimmer may be swimming upstream at 3 miles per hour, but whether or not he gets 3 miles up the stream in an hour depends on the current.

Ground speed is the speed of the plane as measured by points on the ground. This is the air speed plus or minus the effect of wind. A plane flying a course at 100 miles per hour directly into a 25 mile east wind has an air speed of 100 miles per hour and a ground speed of only 75 miles per hour. Should the pilot turn around and fly the opposite direction at the same speed, the wind would now be behind him. His air speed would still be 100 miles per hour but his ground speed would be 125 miles. If the pilot flew a course at an angle to the wind his air speed would remain constant while his ground speed would be somewhere between 75 and 125 miles per hour depending on the particular angle of his course.



HERE ARE THE FACTORS INVOLVED IN DETERMINING WIND CORRECTION ANGLE AND GROUND SPEED

A pilot may determine his own drift while in the air by the use of the *drift sight,* a simple avigation instrument. The sight is mounted in the floor of the plane so that the pilot can look down through it. The drift sight is a calibrated mount and grid ring. This ring can be rotated till the pilot sees objects on the ground move along the lines of the grid wires. Then he merely reads the angle off the scale.

There are several types of drift indicators. These can only be used when there is good visibility. When the sky is overcast and the ground invisible the pilot must depend on radio data to help him determine his drift. Having determined the drift angle, the pilot must correct for its effect by heading his plane into the wind. He must not merely keep to his compass course but must turn into the wind an amount generally equal to the drift angle. This provides a solution to the wind problem and results in a final compass heading on which the pilot may steer.

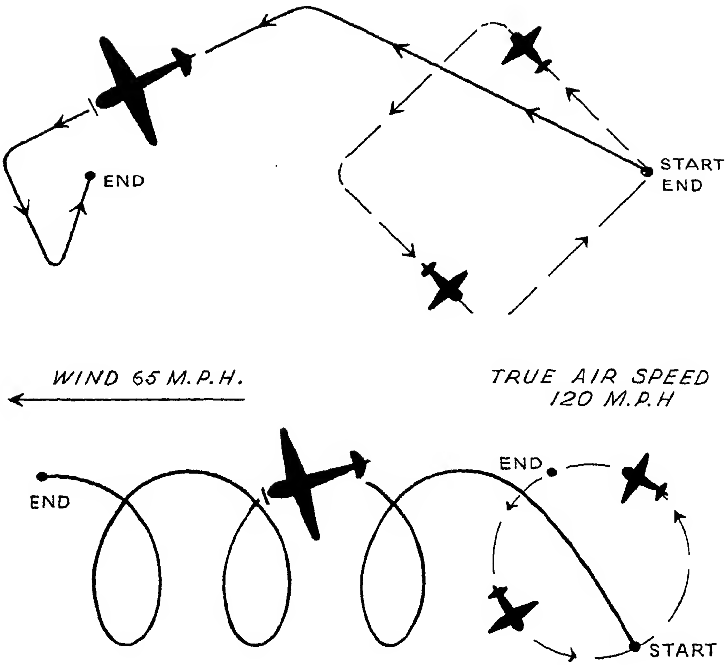
The correction is actually not as simple as this in practice and the pilot may have to check several times to make sure of his

drift direction. Winds coming from a direction within 75° of the nose of the plane require a wind correction less than the observed drift angle. At about 80° the drift angle correction is satisfactory. At angles greater than 80° the wind correction is greater than the observed drift.

Before leaving the ground the pilot can obtain the wind direction and velocity at any desired altitude from the airport meteorologist and can compute his drift and ground speed in advance. The method used is known as the solution of the "triangle of velocities." Instead of using mathematics, most pilots spin the dials of an air navigation computer. This instrument includes a circular slide rule and dials for direction, speed, and drift. With this device the pilot quickly solves his problem.

If the wind direction and velocity change while the pilot is aloft, he will have to make further corrections. If he changes his air speed, his drift correction will not hold true. Of course, the pilot cannot go through all this computation while in the air. He often determines his compass heading before he starts and, if corrections are necessary in the air, he has tables to assist him after he has checked his drift. You can see from the illustration how a high wind will affect the course of a pilot who neglects his drift. According to his instruments he may be flying in a square or circle. The diagram shows the actual path of his plane as altered by the wind.

The plotting of a course through all stages from the true course to the compass heading has been described in a very simple way—not in enough detail to enable you to handle the

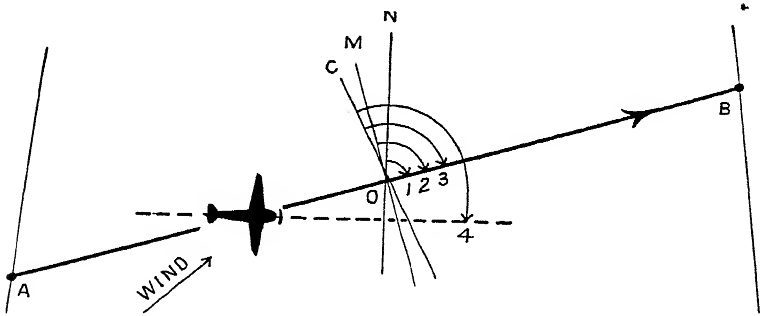


IF HE FAILED TO ALLOW FOR WIND, THE PILOT THINKING HE WAS FLYING IN A SQUARE OR CIRCLE WOULD ACTUALLY BE MAKING THE COURSE ILLUSTRATED

problem professionally, but enough to let you understand what is involved and to permit you to practice yourself. With this method you can plot a course that will get you anywhere in the United States. You appreciate that plotting the course is not the same as flying it and the pilot in the air has a lot more to worry over than you have with a chart and pencils at your

desk.

You also realize that this method of plotting a course is a one-way method. You start out with a true course and figure how to go in order to fly to the desired destination. Sometimes the pilot has just the opposite problem. He knows from his compass which way his plane is headed and from his drift sight which way it is drifting. The pilot wants to know the true course he is following. Without going into detail, his problem is practically the reverse of that mentioned in this chapter. He first has to go back from a compass course to magnetic and from magnetic to



HERE ARE THE TERMS USED IN DEAD RECKONING AND PLOTTING COURSES:

N—TRUE NORTH
M—MAGNETIC NORTH
ANGLE NOM—MAGNETIC VARIATION (WESTERLY)
C—COMPASS NORTH
ANGLE 1—TRUE COURSE
ANGLE 2—MAGNETIC COURSE (VARIATION)
ANGLE 3—COMPASS COURSE (DEVIATION)
ANGLE 4—COMPASS HEADING (WIND)
AB—TRACK

a true course. The true course is corrected for wind drift and may then be plotted on the chart.

There are four basic methods of avigation. The elementary method is that of contact flying or piloting. This makes use of visible landmarks in directing the plane. Radio navigation and celestial navigation are basic methods for airway and distance flights that you will read about later. The fourth method is that of dead reckoning. The name is misleading. There is nothing dead about the method. The correct name is deduced reckoning since the position of the plane (or ship) is deduced from calculations of the pilot. In nautical papers this deduced reckoning was abbreviated to ded. reckoning, and sailors and pilots ever since have altered the abbreviation to dead reckoning.

This chapter has illustrated one important method in dead reckoning. The pilot determines from a chart and other data the compass heading he must fly. Another important dead reckoning method is to determine the true course of a plane in flight from the observed compass direction and the air speed. Dead reckoning is actually determining position by means of direction and distance from a known point. By means of dead reckoning the pilot can answer such avigation questions as these: How far from the airport can I go and return on twenty gallons of gasoline? How long will it take me to fly from Chicago to La Guardia Field with a cruising speed of 180 miles and the wind blowing 40 miles per hour at 160°? What course shall I take to intercept a plane flying 285° at 130 miles per hour if my plane does 210 miles per hour and I leave two hours later from an airport

Official Photograph, U. S. Army Air Forces

PILOTS PLAN THEIR ROUTE BY DEAD RECKONING BEFORE THEY TAKE OFF

168 miles south? These questions sound complicated and they are, but navigators of Navy planes on a carrier solve even more difficult problems by dead reckoning so they can carry out their patrols safely and return to their moving base.

More advanced books on avigation will show you in detail how to solve these and other dead reckoning problems. Pilots consider dead reckoning important because it is the essence of good planning. When dead reckoning is used, other aids to avigation give the pilot frequent checks on his calculations.

A person who knows maps, charts, and directions has a good

start in avigation. A knowledge of dead reckoning and plotting courses is further progress. If you understand these essential topics then you are ready to find out about instruments, practical aids, and meteorology.

8

THE ATMOSPHERE

PLOTTING a course is one thing—flying it another. Every pilot knows the vast difference that exists between theory and practice—the difference between a plotted course and the course as flown.

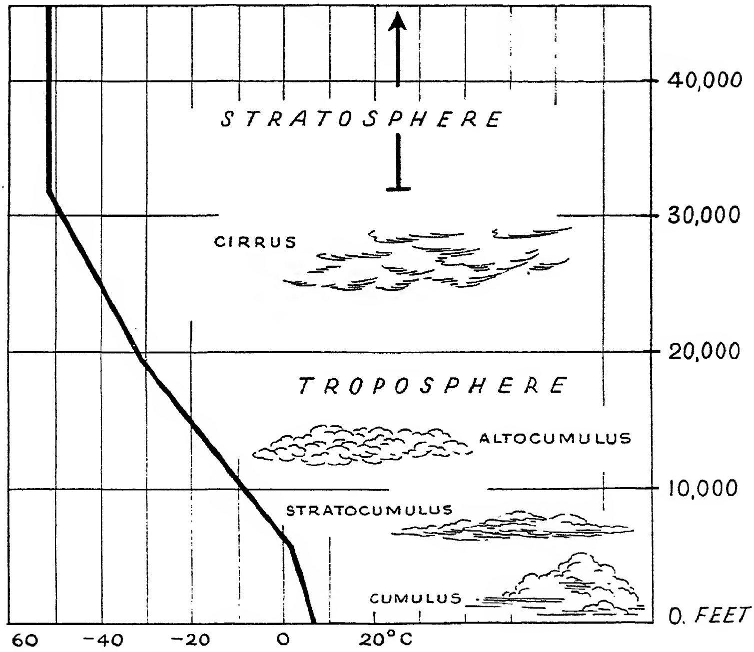
Often the earth makes this difference. Winds, fog, snow, and ice can directly affect avigation if they do not nullify flight plans entirely. Contact flying must be limited to preferred weather conditions. The ceiling must be at least 1,000 feet with a 3-mile visibility. For instrument flying the pilot is not so hampered by lack of visibility, yet rules will not permit an instrument pilot to go aloft when the ceiling is below 500 feet and the visibility less than 1 mile. Even with radio and other aids planes cannot disregard weather conditions. It is true that landings have been made in heavy fog. Fliers have fought their way through thunderstorms and squalls. Yet, all in all, risks are not worth taking and the meteorologist is right in refusing to permit a pilot to go aloft when weather signs are bad. The sky over the airport may look clear to you, but if the meteorologist's reports indicate that a storm is imminent, he may keep planes grounded.

The pilot not only has to use the data furnished by the meteorologist at the airport but has to supplement this information with his own knowledge and observation while in flight. He must understand the meteorologist's language and must be able to interpret the weather for himself. This means he must be able to read weather maps and instruments. He must know the significance of clouds and changes in wind and air pressure. In short, each pilot must be his own meteorologist just as he must be his own map expert. A knowledge of meteorology is required for a pilot's license and major airlines give their pilots further weather training.

The earth is a tiny blob about one millionth the size of the sun, spinning around it at a distance of about 93,000,000 miles. Of the vast flood of energy that our parent star pours out into space, the earth receives but an infinitesimally small part and about 40% of this is reflected back into the void beyond. Yet the energy that reaches the earth is tremendous in worldly figures. This energy heats the atmosphere. It produces winds, clouds, rain, and snow. Solar energy is the force behind the weather. The effect of this energy as it is dissipated through the air is modified by the rotation of the earth and the movement of the earth around the sun. These movements produce changes in wind direction and the seasonal changes in temperature, wind, and rainfall.

The atmosphere in which these phenomena we call weather take place is a layer of gas that completely surrounds the earth. This layer extends outward into space for an unknown distance

—possibly 600 miles. But the air is not evenly distributed through the vertical distance. Half of the total amount of air (the atmosphere weighs over 5 quadrillion tons) lies within three and a half miles of the earth's surface. Half of what is left is found in the next three miles, and so on. Meteorologists are not greatly concerned with the tenuous atmosphere extending out to the farthest limits. They are interested in the lower



THE TEMPERATURE OF THE AIR DECREASES WITH ALTITUDE. THE STRATOSPHERE BEGINS WHERE THE TEMPERATURE CEASES TO FALL WITH HEIGHT

layer where the air is dense enough to produce weather phenomena. This layer, the layer of storms, is known as the troposphere. It generally extends to heights of five to eleven miles: lowest over the poles and high above the equator. Most flying takes place through the bottom half of the troposphere.

The physical and chemical characteristics of the atmosphere control the distribution of solar heat and hence the weather. The atmosphere has weight because it is composed of untold billions of molecules of nitrogen, oxygen, water, carbon dioxide, and other less important gases. Winds keep the atmosphere constantly mixing so that all the component gases remain proportionately the same—at least in the lower levels of the troposphere: about 79% nitrogen, 20% oxygen, and 1% carbon dioxide and other gases.

Of the constituents of air, important in weather, water is the only one that varies considerably. The water content of air may vary from nearly zero to about 4%. Water in the air is usually in the form of water vapor, an invisible gas like nitrogen and oxygen. When this water vapor condenses, it forms clouds, rain, or snow. Actually a cubic foot of moist air weighs less than a similar volume of dry air. Water vapor is lighter than either oxygen or nitrogen and hence air containing more water vapor is a trifle lighter, too.

The weight of the air causes it to press on the surface of the earth and on all objects submerged in it. The pressure is great—somewhere between 20 and 30 tons on the body of every person —14.7 lbs. on every square inch of surface at sea level. This is

another way of saying that a column of air an inch wide, an inch thick, and extending up to the farthest reaches of atmosphere weighs 14.7 lbs. This is generally so. But if you weighed the air in a place where it was moving downward—being compressed—it would weigh slightly more. When air moves upward the resulting weight is less. Pressure is a manifestation of weight. We would be saying the same thing if we said that the pressure of downward-moving air is greater and of upward-moving air is less.

Since the pressure of air is nothing more than weight of air above a point, it stands to reason that the pressure on a mountain top will be less than the pressure at sea level merely because there is less air above the mountain. Repeated measurements have always shown that pressure decreases with altitude. The barometer, the instrument that measures the pressure of the air, can also be used to measure height above sea level. When the barometer is calibrated to measure altitude directly, it is called an altimeter. There is at least one altimeter in every plane.

It is a well-known fact that most substances, including air, expand when heated. Warm air takes up more room (per unit of weight) than cold air. A warm mass of air is lighter than cold air surrounding it, and under usual conditions will rise. Cold air sinks for the opposite reason. However, as warm air rises it gives out heat and becomes cooler and as cool air descends it is heated by compression and becomes warmer. For dry air this heating and cooling due to compression or expansion

amounts to $5\frac{1}{2}°$ F. for every 1,000 feet of change. The wind blowing over the crest of the Sierra Nevada Mountains in California into Death Valley, 10,000 feet below, may be heated as much as 55° in its descent. Air at freezing temperature, 32°, on the mountain crests might be warmed by compression to 87° by the time it reached the valley floor. When air is moist this rate of heating or cooling is retarded.

Movements of masses of warm and cold air are the most

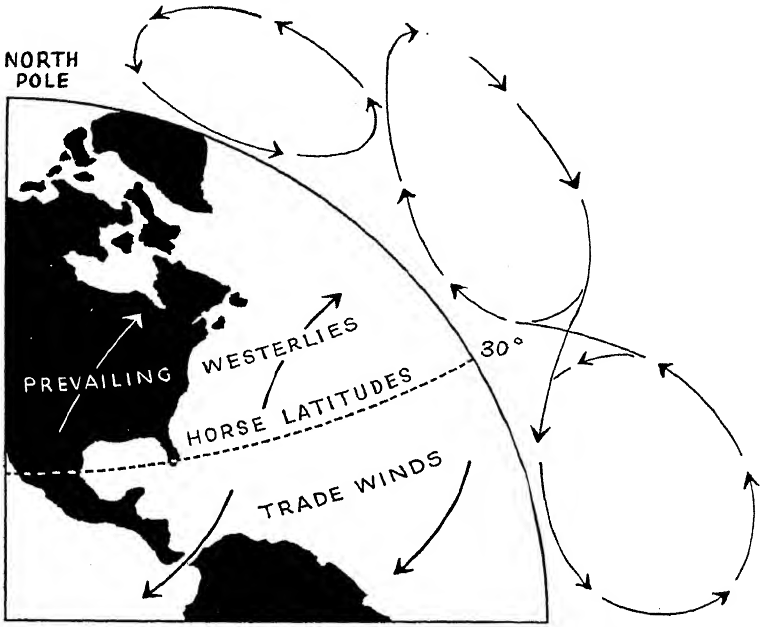
Courtesy of Transcontinental and Western Air, Inc.

USING DATA RECEIVED BY TELETYPE THE METEOROLOGIST PLOTS THE POSITION OF AIR MASSES ON CHARTS

important determinants of weather. The core of the meteorologist's job is to study, understand, and predict the movements of these air masses and their effects on each other. The methods of air mass analysis were developed by Norwegian meteorologists. Previously, only weather on the earth's surface was studied. The new method considers three-dimensional masses of air and gives a truer picture of weather than was hitherto possible. Air mass analysis was introduced here only twenty-five years ago and was quickly adapted to conditions in the United States.

The basis of all weather is exceedingly simple. The region of the earth near the equator is heated more than the polar regions. This causes weather, which is nothing more than all the processes involved in overcoming this inequality. In this heated equatorial region the air is heated also. It expands, becomes relatively lighter than the surrounding air, and rises. Cooler air flows in from north and south replacing the ascending air, and producing steady winds blowing toward the equator from both the northern and southern hemispheres. The heated air rises several miles, cools, and flows north and south at this upper level in directions just opposite to the surface winds blowing towards the equator. Later this air descends and begins to move back toward the equator along the surface of the earth.

This simple picture of wind and weather is disrupted by many complications. First the earth rotates. This spinning swings the atmosphere with it. The winds blowing towards the equator are shifted to the right in the northern hemisphere and to the



THE UNEQUAL HEATING OF THE EARTH CAUSES THE AIR MOVEMENTS THAT MAKE THE WINDS

left in the southern. Most of us have heard about the famed trade winds that steadily blew Columbus toward his goal. These northerly trades blow southwest in a belt extending 30° north of the equator. If the earth were not spinning, these trade winds would blow directly south.

This is only the first complication. Next come the seasonal effects. Only in the spring and fall does the region at the equator receive the greatest heat. As the earth goes on its an-

nual journey around the sun, the direct rays from that important star gradually strike farther and farther north till, at the end of June, they hit the earth 23° north of the equator. Slowly the angle decreases. In September the direct rays are over the equator again but by Christmas they fall 23° south. The belt of rising warm air migrates north and south with the sun. Changes in winds, rainfall, and climate follow the seasons.

There are further modifications due to the fact that ground surfaces heat and cool faster than bodies of water. Hence the air over large continental masses undergoes greater temperature changes than air over the oceans. Then also, mountain barriers limit air movement. The temperature of ocean currents affects winds and rainfall along the Pacific Coast and other places. There are additional factors of weather and climate produced by conditions of the land or the atmosphere in local areas.

All this adds up to a turbulent, mixing, dynamic atmosphere, more difficult to understand and predict than if the circulation were a simple, unmodified, planetary type. It is to the credit of meteorologists that they are undaunted by the complication of factors determining the weather. By careful analysis of records kept diligently for years, the basic and seasonal trends of weather are fairly well known. Reports and maps prepared at least four times daily keep the meteorologist posted on the specific conditions of the air masses that may affect his station. At critical times he may receive an almost continuous stream of weather reports.

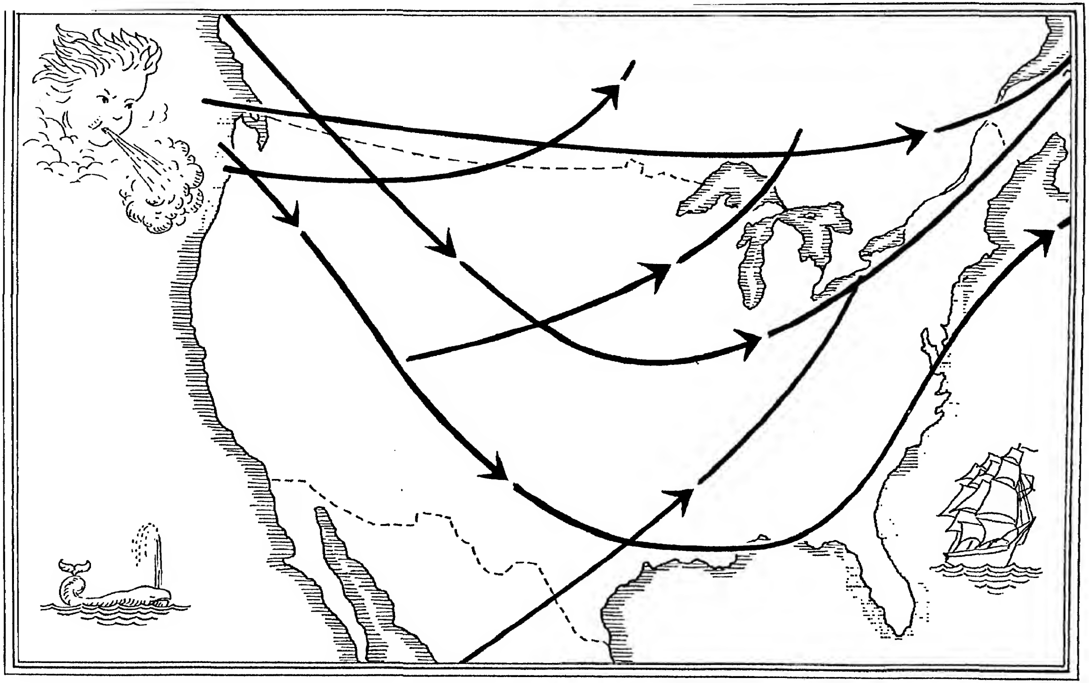
Because of his training, the meteorologist can predict the

weather up to 36 hours in advance with accuracy that often exceeds 95%. He can foretell wind direction and velocity, visibility, the possibility of rain or snow and the height of ceiling. He can tell in advance what kind of cloud formations to expect, the probable temperature within 3°, pressure and moisture in the air. He will let you know whether these conditions are steady—and if they are changing he will have an idea as to what the changes may be. When conditions are favorable he may extend an accurate forecast to 72 hours.

So much depends on accurate weather forecasts that meteorologists of the Weather Bureau, Army, Navy, and airlines are all jealous of their accuracy records. At the end of every flight, TWA pilots report on the actual weather during the trip. This is compared to the flight prediction given them on their departure. The airline meteorologists, who use their own and Weather Bureau data, are proud of an accuracy record of 98%.

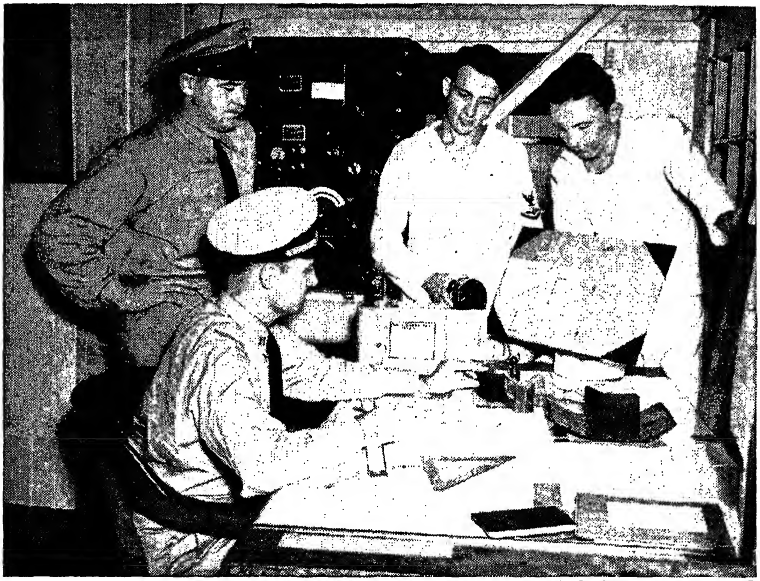
The airlines just have to have accurate data. On one hand they carry U. S. air mail, and the mail must go through if there is any chance at all. On the other hand, airlines also carry passengers. They know that the highest safety standards are essential for passenger travel. To do both the air mail and the passenger job well, the airlines can't afford to make mistakes and their enviable records of millions of passenger miles without accident tell more than words.

This accuracy is not a matter of luck, but of almost perfect scientific co-operation. Along the civil airways there are over 500 U. S. Weather Bureau Stations. There are an additional 300



KNOWING THE TYPICAL PATHS OF STORMS ACROSS THE UNITED STATES, METEOROLOGISTS CAN ACCURATELY PREDICT THE WEATHER AT LEAST 36 HOURS AHEAD

or so at other strategic points. The Army, Navy, and most air-lines have their own stations. In addition, data are received from stations all over the world and from ships at sea. Every pilot reports back by radio any changes in the weather that he thinks the meteorologist at the airport should know. Many stations take observations aloft by means of pilot balloons that show wind speed and direction at high altitude. Some stations use a unique balloon-carried-radio-reporting-weather-bureau known as radiosonde. At major airports, meteorologists are on



Official U. S. Navy Photograph

THE RADIOSONDE APPARATUS CARRIED UPWARD BY A BALLOON AUTOMATICALLY REPORTS WEATHER CONDITIONS ALOFT

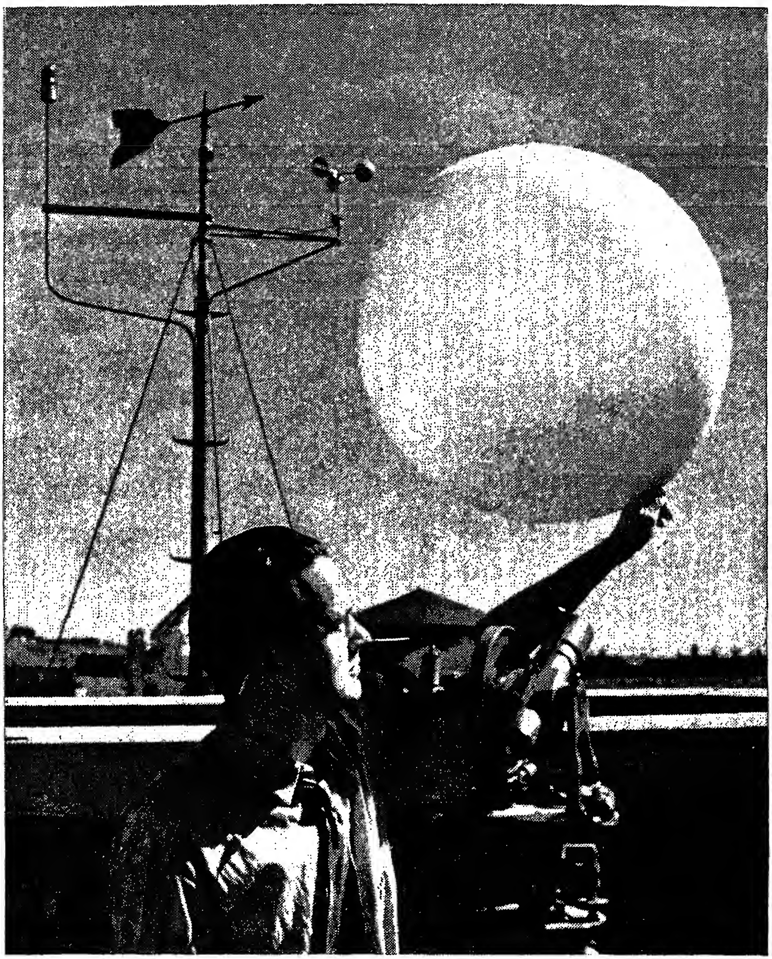
duty twenty-four hours a day. The facts about weather are studied by trained experts who prepare weather maps and predictions from the data.

However, this is not the story of the exciting and valuable work of the Weather Bureau and airline meteorologists. We have to confine ourselves to the facts that these methodical scientists have gathered for us.

Weather data of practical value to the pilot deal with facts related to the following: clouds, rain, snow, sleet, hail, storms of several types, obstructions to vision, such as haze, fog, dust, smoke, and wind. Pilots also need to know the barometric pressure, temperature, dew point, and occasionally ice conditions. These are not the only factors involved in weather, but these are the most direct concern of the avigator. About each of these factors a number of pertinent facts must be secured. The pilot must know the wind direction, velocity, character, and shift. The kind of clouds, amount of sky covered, and changes in cloud formation may also be important.

Literally hundreds of weather reports are received at an airport weather station daily. Speed is essential if they are to be interpreted and made available to pilots. Transmission of facts about the weather in the simplest and most direct manner is accomplished by a code with which every meteorologist and most pilots are familiar. Like any code it seems mysterious and unintelligible at first sight.

Who wouldn't be puzzled if he were handed the following—just off the teletype machine:



Courtesy of Transcontinental and Western Air, Inc.

FOLLOWING THE BALLOON WITH A SPECIAL TELESCOPE, THE METEOROLOGIST GETS DATA ON WIND SPEED AND DIRECTION AT UPPER ALTITUDES

WA N SPL 1624E E30 ⊕ 15 ⦶ 2V TRW-BD- 152/68/60 →↘22 +↖ 1618E/996/+ ⊕ NW OCNL LTNG IN CLDS

The experienced meteorologist would translate this meaningless line of letters, numbers, and symbols as follows: "Washington—observance of instrument flight rules required; special report at 4:24 P.M., Eastern Standard Time; ceiling estimated at 3,000 feet; overcast, lower scattered clouds at 1,500 feet; visibility 2 miles, variable; thunderstorm; light rain shower; light blowing dust; barometric pressure 1015.2 millibars; temperature 68° F.; dew point 60° F.; wind west-northwest 22 miles per hour, strong gusts; moderate wind shift from the south at 4:18 P.M., Eastern Standard Time; altimeter setting, 29.96 inches; dark overcast to northwest, occasional lightning in clouds."

Believe it or not, all that information is conveyed in the line of code—and messages such as these come in hour after hour from nearly a thousand stations. No wonder the meteorologist has the facts about the nation's weather at his fingertips. The code is not so difficult as it looks. Complete directions for its use are found in *Weather Bureau Circular N 1941* where they can be studied in detail. Just a few examples show how it works.

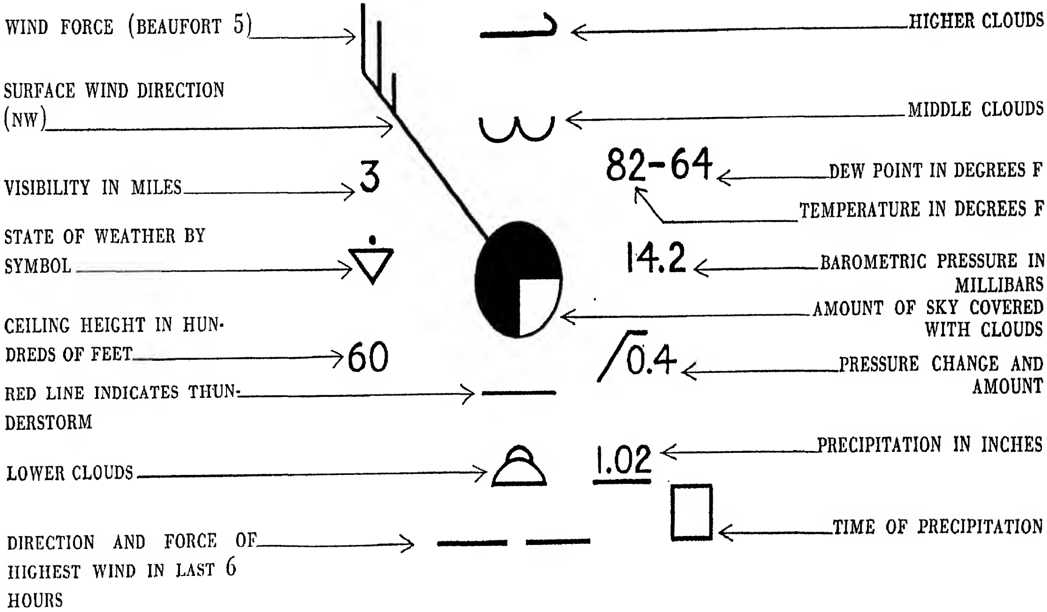
The first two letters WA stand for the station, Washington, D. C. If the report came from Baltimore it would begin BO or from Chicago CG. The next letter sums up flying conditions. C indicates weather suitable for contact flying. N means that conditions permit instrument flying only. X means all aircraft

aground.

The Weather Bureau uses the twenty-four-hour clock to tell time. So do the Army, Navy and many foreign countries. This clock avoids the mixups that come with A.M. and P.M. Time is recorded in four numbers—the first two being the hour and the second two the minutes. The day begins at midnight; 0630 is 6:30 in the morning; 1210 is ten minutes past noon; 1800 is 6 P.M.; and 2345 is a quarter to midnight. The letter E after the time numbers indicates Eastern Standard Time. C stands for Central Time, M for Mountain, and P for Pacific Time.

The combination of arrows and numbers gives the wind direction and velocity. Arrows show the direction from which the wind blows as ↓ shows a north wind and ↑ wind from the south. Sixteen combinations are possible, including the one in the code example →↘ meaning a wind from west-northwest. The number following the arrow gives the wind velocity in miles per hour. A minus sign after this indicates the wind is blowing in fresh gusts and a plus sign means strong gusts. The number alone signifies a steady wind at that speed.

The data from the various stations are plotted on a map using standard symbols to show the conditions at the station. Lines are drawn connecting points of equal barometric pressure and sometimes lines of equal temperature—at the zero and the freezing point. Wind direction, speed, rainfall, pressure, clouds, and other facts are recorded. These synoptic charts, as they are called, are made up every six hours and show a complete picture of the atmosphere at that time. These are supplemented



FOR EACH WEATHER STATION, CONDITIONS ARE INDICATED BY STANDARDIZED SYMBOLS

by hourly reports that post the meteorologist on changes since the last map was made. Besides, some stations map the upper air at various altitudes and issue special bulletins on conditions at each level.

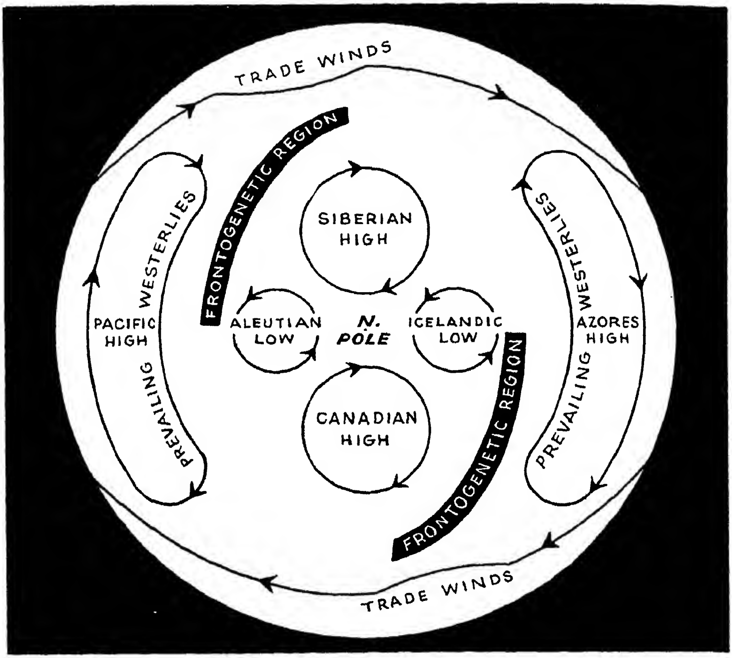
You can see from the brief data in this chapter that meteorology is not a science to be mastered in one easy lesson. The weather is far too complicated and important to be taken for granted or to be studied superficially. The weather knowledge of the average person—usually limited to a few "signs" that may be more superstition than fact—is of little help to a pilot. The next two chapters will serve to introduce you further to the weather and illustrate in a general way the forces involved. It will take further study before you can make your own predictions or even be well versed about the weather. All knowledge must have a beginning and so let us begin by at least getting a clear, though simple, view of what makes weather and why.

WHY THE WEATHER

THE UNEQUAL heating of the earth in general and of continents and oceans in particular produces major air masses whose movements and effects on each other are important for the pilot. These air masses may be either tropical or polar in origin and may develop over land (continental) or water (maritime). Each type has its own properties and characteristics. In general the air in any of these masses is uniform in temperature and water vapor content at a given level. These masses are designated as warm if moving from a warm region and cold if moving from a cold region toward a warm one. The ability of an air mass to absorb or give off heat is of basic importance.

A continental polar air mass lies above northern Canada. There are maritime polar air masses over the north Pacific and over the north Atlantic. Farther south, maritime tropical air masses are found over the south Pacific and over the Atlantic and Gulf of Mexico. The characteristics of these air masses change from summer to winter and they also may be modified by a number of local conditions.

As storms pass from west to east across the United States, the winds moving around the storm center draw in air from these



WARM AND COLD FRONTS ORIGINATE IN THE REGIONS WHERE DIFFERENT AIR MASSES COME TOGETHER

air masses. Air of different physical conditions may be brought into contact. Sometimes these flows of differing air may mix. More often, because of their inherent differences, a sharp zone of contact is formed. Such a zone is called a *front*. The front takes its name from the air mass that is moving in. The front of a migrating cold mass is a *cold front* and that of a warm mass, a *warm front*.

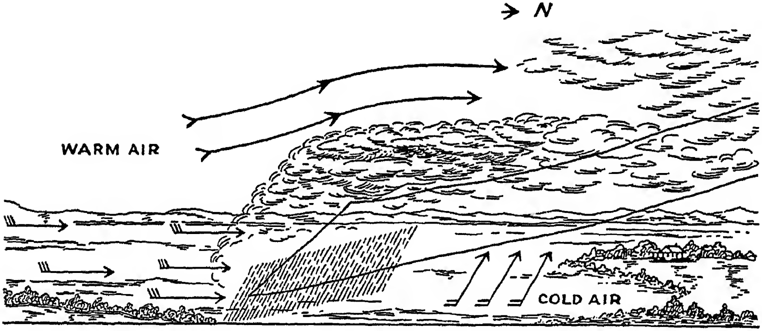
A front may best be pictured as a wedge-shaped mass of air moving above or below another differing air mass. The wedge, of course, is invisible and one can only recognize fronts by the effects produced when differing air masses come into contact. These effects include typical cloud formations, winds, and precipitation.

You recall that the rotation of the earth causes a deflection of the winds of the earth. Air moving toward and away from the equator is deflected. Air moving north from the equator at high altitudes is deflected eastward and builds up a belt of high pressure at about 30° N. latitude. This belt is called the horse latitudes. Polar air is similarly deflected. This polar air meets warmer air being forced north from the high pressure zone of the horse latitudes. At the contact of the polar air and this northward-moving warm air, the *polar front* is formed. This polar front is a region of utmost importance because here is where much of our temperate zone weather originates. Rainstorms, blizzards, and outbreaks of cold air form along the polar front.

The polar air is revolving in the opposite direction to that of the warmer air to the south. You might compare the situation along the polar front with a crowded city street where people are pushing along in opposite directions. Those unfortunates who are walking right along the center, where people going opposite ways are close together, will be bumped and pushed around more than those completely in their own lane. Along the polar front a similar thing happens. The air masses are moving

in opposite directions and at different speeds. Disturbances or *depressions* are formed along the line of contact as these different air masses rub elbows.

If the air masses were colored red and green and you could observe the front from heights of one hundred miles or more in the stratosphere, the origin of these depressions would be obvious. The diagrams illustrate this nearly as well. They repre-

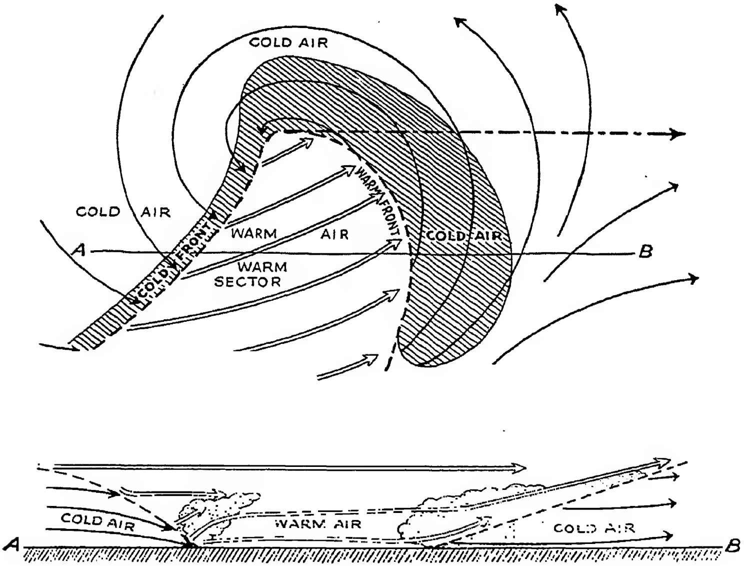


AN ADVANCING WARM FRONT BRINGS A SLOW STEADY RAIN

sent the air masses as viewed from above. As the warm air is bounced in over the cold, a warm front and an area of precipitation form. The cold air begins to sweep around under the warm air forming the cold front. The area of rainfall is extended. The air instead of moving in opposite directions begins to take on a counterclockwise whirling motion. The faster moving cold front begins to overtake the warm front, and when the two meet (the process is known as *occlusion*) the cold front lifts the warm front off the surface of the earth. Sometimes the

cold front rides aloft over the warm because of different density conditions of the air masses. Occlusion results in a complicated arrangement of air masses both on the ground and aloft, giving rise to poor flying conditions. Meanwhile the storm has not remained still—it has moved across the country in a general west-east direction bringing strong changes of weather with it.

When the air is rotating counterclockwise and is moving in and up, the pressure is lowered. On a weather map this area is marked as a *low* and it is known as a *cyclone*. Technically, the lows are called extra-tropical cyclones to distinguish them from

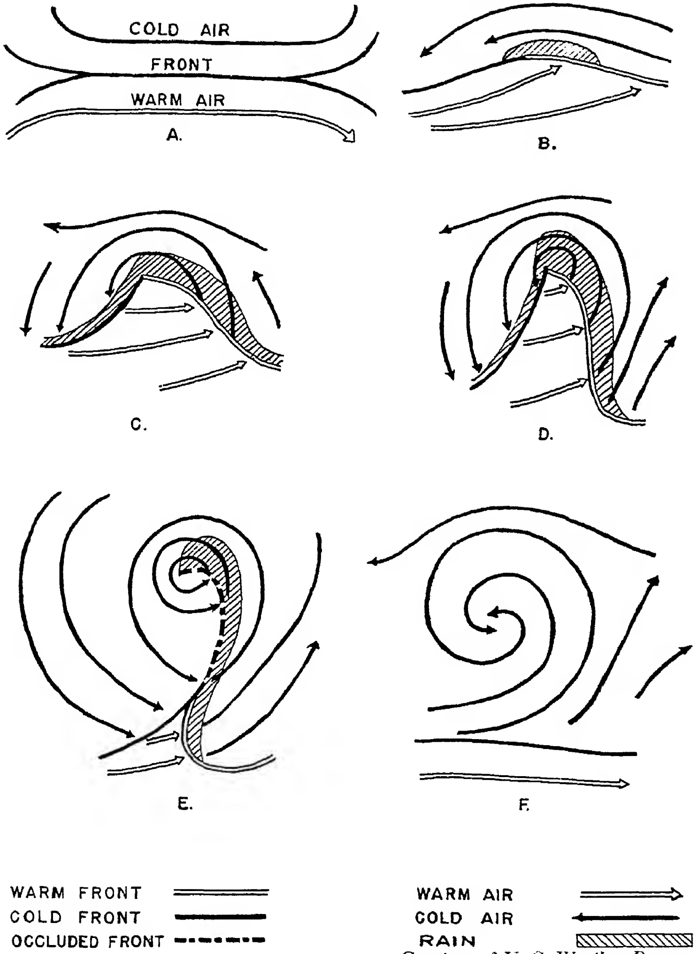


A TYPICAL CYCLONIC STORM AS SEEN FROM ABOVE AND IN CROSS SECTION

the destructive tropical storms of the same name. The lower barometric pressure is indicated on maps by the *isobars*. These are lines drawn on the weather map connecting points of equal air pressure. Around a depression the isobars appear as a series of concentric circles with the pressure decreasing toward the center. When the isobars are close, this indicates a more rapid change in pressure at a given level and usually strong winds and a more severe storm. The winds veering from south to east then north may sweep up warm, moist air northward, causing torrential rains or heavy snows.

These lows—huge whirlpools of air several hundred miles across—move across the United States in rather well-defined paths. The meteorologist, after watching the low for a time, can easily predict which way it will go. These lows curve in different paths across the country. They generally pass over New England before heading out to sea, giving those states more than a normal share of bad weather. Lows move at various rates of speed—generally from 400 to 800 miles per day or roughly about 25 miles per hour over land. Speeds are greater in winter than in summer. So the meteorologist can not only tell where a storm is going, but how fast.

Air also rotates in a clockwise direction and moves downward and out. In these areas the pressure is *high* and is so labeled on the weather map. Technically these are called anti-cyclones because air movement is opposite to that of a cyclonic disturbance. Anti-cyclones also move from west to east and a strong anti-cyclone may bring cold air from northern Canada. The



Courtesy of U. S. Weather Bureau

THE DEVELOPMENT OF A FRONTAL STORM AS SEEN FROM ABOVE

clockwise winds may sweep this far south. Then the resulting cold wave would cause a damaging freeze in the Florida orange groves.

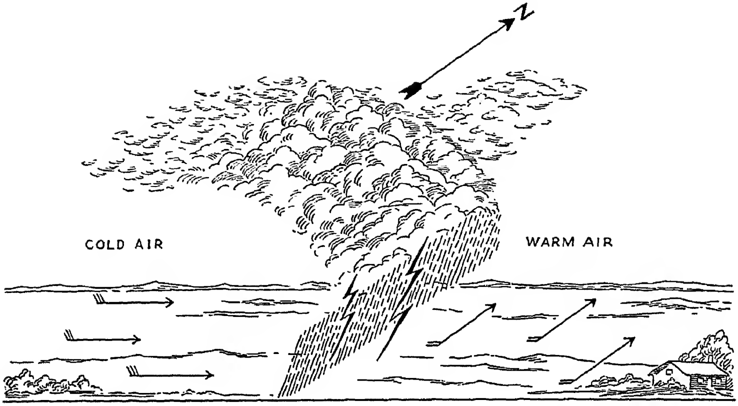
The temperature and moisture content of the air carried along in these large-scale movements depend on the origin of the air mass. For example, consider a few facts about moisture. First, the amount of water that air can hold, as water vapor, depends on the temperature. Warmer air can hold more moisture. Moisture in air is usually expressed in terms of *relative humidity*. This is the percentage of water in the air compared to the maximum amount the air might hold at that temperature. A relative humidity of 75% means that the air now has 3/4 of all the water it can possibly hold at that temperature. If the temperature increases, the air can hold more water—and if no water is added, the relative humidity of the same air mass may drop to, say, 60%.

On the other hand, when air cools, its ability to hold moisture diminishes. Cooling an air mass may raise its relative humidity to 95% or 100%. This last point is the point of saturation and when humidity reaches 100% the water in the air will begin to condense. It may condense into cloud droplets, into fog, drizzle, rain, snow, sleet, or hail depending on the conditions at the moment. This direct relationship of temperature and humidity is exceedingly important to the pilot. Changes in air temperature may produce enough changes in visibility or precipitation to put a halt to flying.

Often the temperature part of this temperature-humidity re-

lationship is stressed. Then the meteorologist speaks of the *dew point.* This is the temperature to which a body of air must be cooled before the moisture in it will condense. When the temperature is 74° and the dew point 63°, a drop of temperature of 11° will bring the relative humidity to 100% and will cause condensation to begin. This is the way dew forms at night. The temperature of the air near the ground drops after sunset, as the earth cools rapidly. When the temperature has dropped below the dew point, moisture from the air condenses on the cold leaves of grass, forming dew. If the dew point is 32° or less, the condensation will be in the form of frost.

These facts begin to draw together into a logical picture. On a hot summer's day the land is heated strongly and so is the air over it. This warm air may hold a great deal of moisture. Because it is warm and light, it rises. Rising, it cools because of altitude and because the very process of expansion results in *adiabatic* cooling. Normally, cooling involves the transfer of heat away from a body. In adiabatic cooling there is no withdrawal of heat. The expansion of the air mass produces this cooling without outside influence. As the air ascends it soon reaches the dew point and condensation begins. The condensed moisture at the top of this ascending warm column of air forms a typical cloud—the cumulus cloud or thunderhead often seen on summer afternoons. These conditions may continue to the point where a thunderstorm with rain and hail results. Thunderstorms form in other ways, too. They are often associated with the warm air being pushed upward along a cold front.



AN ADVANCING COLD FRONT BRINGS THUNDER-STORMS AND SUDDEN SHOWERS

All sorts of wind may be important to the avigator, so he is careful to understand the various local forms as well as the major air movements. The pilot knows that land heats and cools faster than water and that air above it is also heated and cooled rapidly. During the summer's day along the seacoast, as air rises over the land, more comes moving in from over the cooler water producing an "on shore" wind or sea breeze. At night the condition is reversed and the water becomes relatively warmer. The breeze reverses too and blows "offshore." This is a land breeze.

At night cool air rushes down the sides of hills and mountains. If slopes are steep, a strong mountain breeze results. When air is forced over a high elevation and descends rapidly on the other side, the air is heated by compression as it moves

downward. This heating means that the air can take and hold more water. A warm dry wind is produced. Such winds have made Death Valley arid. Because of their rapid descent from mountains over 10,000 feet high, they are so heated that there is very little chance of rain. Similar hot dry winds occur in the Rocky Mountains, the Alps, and along other mountain ranges.

In addition to these and other local winds there are eddies, fall winds, and gusts that occur alongside mountains or obstructions to the moving air. Air flowing over obstructions may be merely "rough," though eddies and down drafts may be so strong as to make flying hazardous. Pilots always take care to avoid flying low in mountainous regions because of this danger.

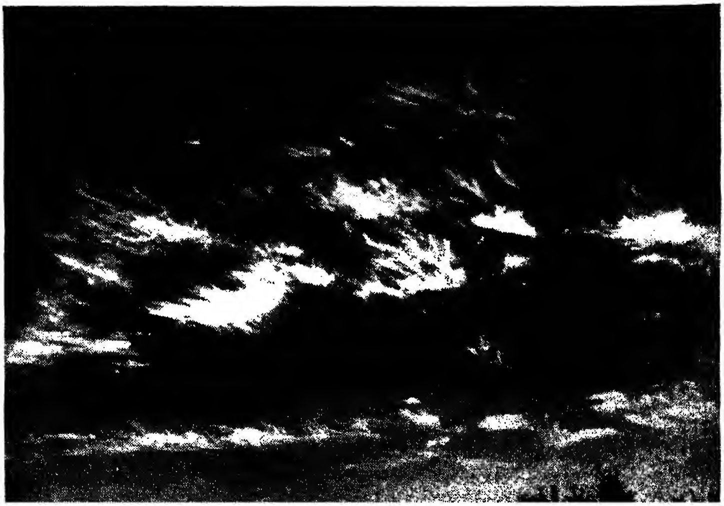
The friction of rubbing against the land, and to a lesser extent the waters, actually slows down the speed of wind at the surface. Only at a height of 2,000 feet above ground (and 500 feet above the ocean) is the friction reduced to zero. For this reason winds aloft are usually stronger than surface winds. Not only is their velocity greater, but direction differs too. In the northern hemisphere, a pilot flying into the wind would find it veering to the right as the plane rose. Aloft its direction might differ from the surface wind by 25° to 90°.

Of all condensation products, fog is often the worst for the pilot. A quick way to define fog is a cloud on the ground. More accurately, it is a condition of poor visibility at the ground due to suspended water particles. Haze is due to smoke or dust. When the particles are water droplets or tiny ice crystals the pilot is in a fog.

The same processes of condensation that produce clouds make fog. The moisture content of the air must increase or the temperature decrease until the dew point is reached. Other conditions are also necessary. The air must contain particles about which the water may condense. These particles may be microscopic specks of salt from the sea or smoke. Wind is also necessary—but only a light one. Fog will not form in a high wind. When warm moist air passes over a cold surface, fog may form. Winds blowing over warm or cool ocean currents produce sea fogs. West winds, cooled by the cold ocean current off California, produce fog when they contact the warm land air. If the cold current disappeared, so would the fogs of San Francisco. Though details may vary, cooling of air by contact or by radiation produces fog.

The meteorologist may predict fog for the pilot when warned by conditions as shown on the weather map. The meteorologist looks for an air mass, moist in its lower layer. If the dew point is near the air temperature and the ground surface is cold, fog may form, especially with a low wind. These conditions are apt to occur in certain sections of the country—along the north Pacific and north Atlantic coasts—and in that special trap for unwary pilots—the Allegheny Mountains.

The other condensation products are easy to understand. The specific form of condensation may depend on the temperature and on the particles available for condensation. The water droplets in fog and cloud average about $1/1000$ inch in diameter. In high clouds these are microscopic ice crystals. When the



Courtesy of U. S. Weather Bureau

THE HIGH CIRRUS CLOUDS ARE COMPOSED OF TINY ICE CRYSTALS

particles are up to $\frac{1}{50}$ inch in diameter a drizzle or mist results. Particles larger than that, when definitely falling, are raindrops.

When water condenses below 32° F., snow or ice crystals form. Water may condense at a temperature very close to freezing and form ice on any cold surface the droplets touch. Sleet is small frozen drops of rain. Hail is a particular form of ice occurring in thunderstorms. Droplets of water are carried upward by ascending air. They freeze, building up hail stones sometimes two inches or more in diameter.

Clouds are a common enough form of condensation, but they

are specially significant to the pilot as they give a clue to coming weather conditions. Sailors have always watched clouds and many weather sayings have sprung up about clouds, some of which are not worth the confidence people place in them. Clouds are easy to observe and from them the pilot may glean last minute information that occasionally is more useful than a weather report several hours old.

The highest clouds are those of the *cirrus* type. These are thin, threadlike feathery clouds, often 30,000 feet high. They may also appear more sheetlike and are then termed *cirrus-stratus*. Lower clouds of the *alto* group vary in height from 10,000 to 20,000 feet. These are the white or grayish clouds that may often cover the entire sky in lines or waves. The individual small clouds blend together into a thin layer called *alto-cumulus*. When the layer is more pronounced and the individual character of each cloud is merged in the mass these clouds are called *alto-stratus*.

Still nearer the surface of the earth are the *stratus* and *nimbus* clouds. The stratus clouds may form a low rolling layer at heights of 2,000 to 5,000 feet. The layer may merge into a heavy gray sheet resembling fog above the ground level. The nimbus clouds are those we dislike most—they are rainclouds: low gray ragged masses without distinct form.

Finally there are the *cumulus* clouds that form as a cap to a rising column of warm air. These are the magnificent, dense, dome-shaped, puffy clouds that you stop to admire on a hot afternoon. They are dark beneath and when they spread to

Courtesy of Transcontinental and Western Air, Inc.

CUMULUS CLOUDS OFTEN MARK RISING CURRENTS OF WARM AIR

cover the sky a thunderstorm is brewing. Meteorologists classify clouds with much greater accuracy, using a standardized system of identification.

Each type of cloud, the transition from one type to another, and the amount of cloudiness in the sky, all tell a story to the meteorologist. When cirrus clouds give way to cirrus-stratus and then to alto-stratus and to stratus, indications for rain are clear. Distinctive cloud formations mark cold and warm fronts. Cloud formations over mountains give a clue as to air movements above the peaks.

Clouds and fog are the usual limitations on *visibility* and *ceiling*. These are very specific terms and have exact meanings to the avigator. Visibility is horizontal—it is the greatest distance toward the horizon at which prominent objects can be identified. Visibility of 10 miles or more is considered unlimited for flying purposes. Less than 1/8 mile is classified as zero. Visibility is checked against the distance of known landmarks and is reported in miles. When visibility is 2 miles or less, it is more accurately reported to the nearest quarter mile.

Ceiling is measured vertically. It is considered unlimited when the sky is clear or clouds are above 10,000 feet. Ceiling zero means either clouds within 50 feet of the ground or heavy fog or precipitation. Measurements with pilot balloons give the height of the ceiling accurately during the daytime. At night, a special projector shoots a beam of light vertically. An observer, at a fixed distance from the lamp, sights the spot of light on the cloud and measures the angle by means of a *clinometer*.

When this angle is known, together with the distance of the base line, the height of the cloud becomes a problem of simple trigonometry.

In the weather reports the ceiling height is reported in hundreds of feet, i.e., 30 standing for ceiling 3,000 feet. The letter E preceding the ceiling number indicates the height was estimated, not accurately measured. V indicates the ceiling height is changeable. It is used when the ceiling is below 2,000 feet. The amount of cloudiness is reported in detail. When less than $\frac{1}{10}$ of the sky is covered, it is reported as *clear*. Clouds are reported as *scattered* when they cover $\frac{1}{10}$ to $\frac{1}{2}$ of the sky; $\frac{1}{2}$ to $\frac{9}{10}$ is *broken* clouds and over $\frac{9}{10}$ is considered *overcast*. The terms high or low may be added—as in "high scattered clouds" or "low broken clouds." The height of the lowest clouds may also be included in weather reports. The measurement is given in hundreds of feet, as is ceiling height.

These are the main factors of the weather. They determine whether the pilot goes aloft or stays grounded. Weather fixes ceiling and visibility and determines drift and ground speed of the plane. The dangers of bad weather—downdrafts, fog, head winds, and ice—give the pilot good reason for taking weather seriously. The meteorologist is a person of importance at the airport. A good pilot recognizes his authority and uses his information. Just how the pilot gets and makes use of weather data and how weather affects a plane we will now consider in more detail.

10

THE PILOT AND THE WEATHER

YOU NOW have enough understanding about weather to ask, "What does the pilot do about it?" The pilot does a lot. Every phase of avigation from plotting a course to landing at a destination is influenced by weather. The pilot soon learns to have a deep respect for the atmosphere because he is at its mercy.

Before going into a detailed answer to the question, just recall that you are still far from being a weather expert. Weather conditions can easily be misleading and the overconfident amateur, who sets himself up as an expert, may really endanger himself and others. It is the experienced pilot who makes full use of the trained meteorologist's knowledge and information, with enough supplementary knowledge of his own to make wise decisions in the air when weather conditions challenge him.

The pilot must be alert for a number of special weather conditions and must understand the general procedures of obtaining and using weather information as well. These special conditions are the fronts, thunderstorms, ice, and fog.

Warm fronts are hazardous because of the wide areas of rain, cloud, and fog that precede the front. Low ceilings and visibil-

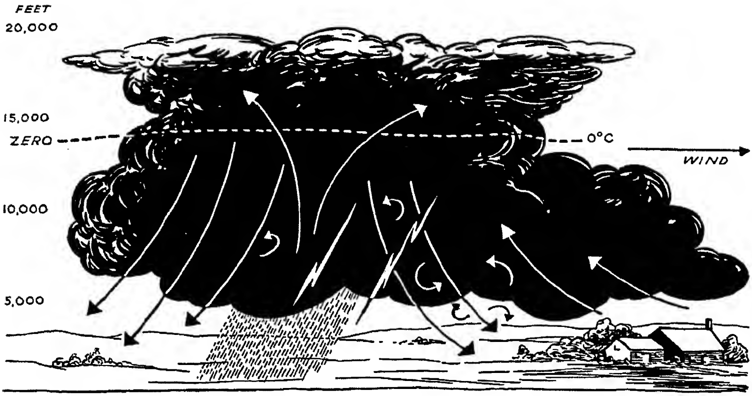
ity may extend for hundreds of miles, grounding planes and making landings difficult. Cold fronts may produce showers, squally weather, ice conditions, and strong winds. Of course, each air mass has its own special peculiarities and details may be hard to determine or predict.

Cold fronts are characterized by a turbulent zone about 50 miles wide along the front. Many aircraft accidents occur in this zone. Air is forced upward with considerable velocity. Thunderstorms may be present and, generally, air conditions are such that it is difficult to keep a plane under control. Pilots avoid crossing or flying along a cold front whenever possible—experienced men may decide to turn back rather than take the risks involved in bucking the turbulent air of a strong front.

Thunderstorms are of two general types: those forming along warm and cold fronts—frontal thunderstorms, and the "thermal" type produced by local heating of an air mass. A strong thunderstorm of either frontal or thermal type is as violent a hazard as the pilot has to fear outside of the tropical hurricanes and tornados.

The thunderstorm accompanies an upward current of warm air several miles in diameter. Air moves up so rapidly and in such large amounts that raindrops are often blown to bits and the smaller particles are carried upward, freezing at higher altitudes to form hail. Air around a thunderstorm is unstable and, while the storm itself indicates a readjustment, the adjustment itself is violent.

Inside the cumulus and cumulo-nimbus clouds that form the



THIS CROSS SECTION OF A TYPICAL THUNDERSTORM SHOWS THE UPDRAFT, DOWNDRAFT, AND TURBULENCE

thunderhead are strong updrafts that may attain velocities up to 200 miles per hour. One pilot reported his plane was lifted violently while he was diving through such an updraft. There are also downdrafts in this whirlpool of air. Some are within the cloud and others around it. The cloud itself contains water in all three of its physical forms—as a gas, water vapor; as a liquid, water droplets; and as a solid, ice crystals. The ice crystals are generally confined to the upper parts of the cloud, the droplets to the lower sections with a mixing of ice and water droplets in between. It is the mixing of the ice crystals and water droplets that starts precipitation and produces the sudden torrential rains often occurring with thunderstorms. The mechanism of thunderstorms is such that there are often two distinct rains: a primary rain or hail with large drops and heavy

flow; a secondary rain which comes later is less intense and the size of the drops is smaller. Next time a thunderstorm is brewing, take the time to observe it carefully and note the stages in its life history.

The pilot is more interested in the dangers of thunderstorms than in their majestic beauty. He knows that hail can do serious damage to a small plane. Lightning and ice are hazards, too. So are the strong winds and turbulent air. Not all thunderstorms are accompanied by hail—but one-quarter or perhaps one-third of them are. In less than 1% of thunderstorms do hailstones get large enough to damage a plane; but when they do, the damage may be serious. Lightning also is not a serious source of danger, but occasionally planes are struck. Radio sets have been destroyed by the stroke, but otherwise lightning is probably more bark than bite. It is quite obvious that avigators can avoid lightning if they avoid thunderstorms. If near a thunderstorm they should avoid instrument flying, especially through cumulus and nimbus clouds. The danger of lightning seems greatest when the air temperature is within 10° of freezing.

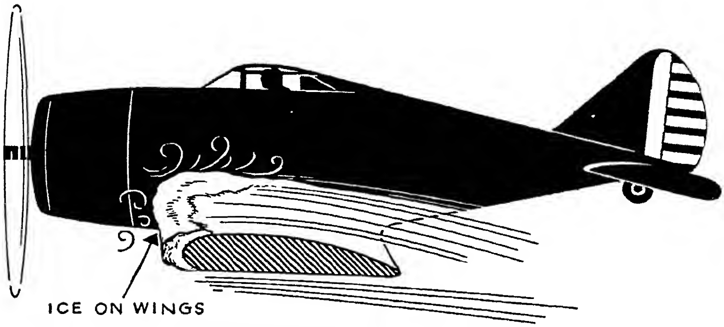
As for the winds and turbulence around thunderstorms—pilots agree that these are a serious danger to all planes. It is difficult to fly over a severe thunderstorm because the updraft continues to great heights. The only safe rule about flying a thunderstorm is *don't*.

These hazardous air conditions are somewhat related. Thunderstorms and cold fronts may be coexistent and the conditions

that favor icing may also be present. For a long time, ice was a lurking menace to all who flew. Ice can drag a plane down with a gigantic irresistible hand. Ice not only affects a plane by its sheer weight but in other more important ways. The efficiency of a plane—or its lift—depends on the special curve of the wing known as the *air foil.* This particular curve is the keystone of the plane. A flat-winged model would never leave the ground. Herein lies the principal danger from ice. The ice formation develops on the front of the wing and because of its shape destroys the curve essential to the lift of the plane. Ice may also affect the propeller and accumulate on struts and wires, increasing their resistance. Planes have been forced down within ten minutes after icing began. Even the pneumatic de-icers on the larger planes are not a perfect solution to the problem, though, without a doubt, they have saved many a plane from a crack-up.

To form ice there are two essentials—water and a temperature below freezing. Both these conditions may be easily attained during flight. Over the Appalachian Mountain region of New York and Pennsylvania icing is common. Low pressure areas bring in moist air from over the Great Lakes. The mountains, because of their altitude and their effect on air, are often characterized by sub-freezing temperatures. This area has been termed "the graveyard of the air" because of the flying dangers over the isolated ridges.

The question of ice formation on the wings of planes has more to it than the basic factors of moisture and cold. These condi-



ICE THAT FORMS IN MOIST AIR AT LOW TEMPERATURES IS STILL A GREAT DANGER TO AVIATORS

tions will usually produce snow or sleet. Why is ice formed at all? To answer this question completely it is necessary to go deeply into the properties of the different physical states of water. Suffice it to say that under certain conditions water may be "supercooled"—cooled below the freezing point—without changing to ice. As soon as the conditions are altered, ice forms immediately. These intricate relationships make it possible for water droplets to exist at below zero temperatures or ice to form on a plane's wings even when the temperature is slightly above the freezing point. Ice usually forms at temperatures between −5° and 34° F. It forms most rapidly at about 20°. Very cold air is often so lacking in moisture that ice will not form. Pilots take advantage of this and climb to higher, colder altitudes when ice conditions threaten.

Ice forms not only on the wings but on the propeller and fuselage as well. Beside its major effects on the wings and pro-

peller, ice may clog instrument tubes and render such essential mechanisms as the speed indicator and gyro instruments useless. Ice may clog superchargers and carburetors, thus directly affecting the engine. Engine icing is a special danger since it may occur even before ice appears on the flying surfaces. Ice increases resistance of the plane. It may affect the rudder and other controlling surfaces. It may cause vibration and possibly structural failure.

During winter and spring along cold fronts, the advancing wedge of cold air forces warm moist air aloft. The warm moist air may be supercooled or a freezing rain may result. Ice commonly forms under such conditions. Icing occurs in stratified clouds or fogs when temperatures are low. The small droplets may form *rime,* a light granular ice or the more dangerous clear ice. Ice may frequently form over mountain areas. The mountains force air upwards making each mountain ridge a zone of potential danger.

The pilot must be especially alert for these weather conditions that cause flying accidents. In addition there are many other factors involved in planning and carrying through a normal flight. In making flight plans the pilot has to choose between contact and instrument flying. This may depend on the equipment of his plane, on his experience, as well as on the weather. If he is trained in instrument flying and if his plane has proper equipment, then the pilot may take off under conditions that would ground a contact flier.

In making plans for a flight, the pilot consults the airport

bulletin board for the latest weather maps and reports. If he needs further facts he consults the meteorologist on duty. From the reports he gets ceilings and visibility along his route and at his destination. He also looks up alternate routes and alternate landing fields in case weather conditions close the airport to which he is headed. The pilot finds out surface winds and winds aloft. Without knowing the latter he cannot estimate his ground speed, flying time, and fuel needed. Knowing wind, he can make dead-reckoning calculations for his flight. Then, as you already know, he checks for weather hazards—ice, thunderstorms, or rough air.

The major airlines assist the pilot in this because of the great responsibility involved when carrying passengers and mail. TWA, for example, has its own meteorological staff of twenty-five or so men on continual duty. Using their own and government data these men prepare advisory forecasts and specific trip forecasts. When the TWA pilot signs his flight report he indicates he has read and considered the weather report that is included in it. During flight the pilot gets fresh weather reports by radio and on his flight report he notes the actual weather conditions encountered. TWA meteorologists make about 125 trip forecasts daily and handle over 20,000 weather reports a month.

Every pilot knows that weather conditions change; that storm centers shift; that fronts may change in intensity. Unless a map has just been made or a report just issued, it may not show the true state of the weather which changes from hour to hour. In-

Courtesy of U. S. Weather Bureau

THE TELETYPE SYSTEM BRINGS NEWS OF THE WEATHER FROM EVERY SECTION OF THE COUNTRY TO THE MAJOR AIRPORTS

volved in these changes are wind velocity and direction, storm paths, pressure gradients, time of day, local topography, and several other factors. When he knows the facts, the meteorologist extrapolates—or extends forward—the weather data, bringing conditions right up to the minute. This is a serious job as it involves a knowledge of local conditions as well as an understanding of weather and the path and speed of storms.

It is at this point that the pilot often needs his own weather knowledge. Only at the largest airports are meteorologists on constant duty. The pilot may be in places where he must make

his own interpretation of the last map or report and must visualize for himself the weather aloft.

The pilot's decisions have to be based on a good deal of thinking in terms of the weather. Suppose a pilot is making a fairly long west-east flight over ground dominated by a low pressure area. The wind directions around a cyclonic disturbance are such that by flying on the north side of the low the pilot will buck headwinds; flying on the south side, tail winds will hasten his flight. But flying to the south will take the pilot across the cold front and bring him into turbulent air and perhaps into storm and rain—at best he will be flying with a low ceiling and visibility.

In flying a northward track, a pilot headed east of a low would have storm conditions. Winds would not be as favorable along the west of the low but the weather would be clear.

In keeping up to the minute with the weather, the pilot can count on radio aids. Broadcasts of weather data take place hourly on a definite schedule. These schedules are printed on the sectional aeronautical charts as part of the aeronautical data. The Seattle data appear on the map as follows:

K C Z 260 S A . —

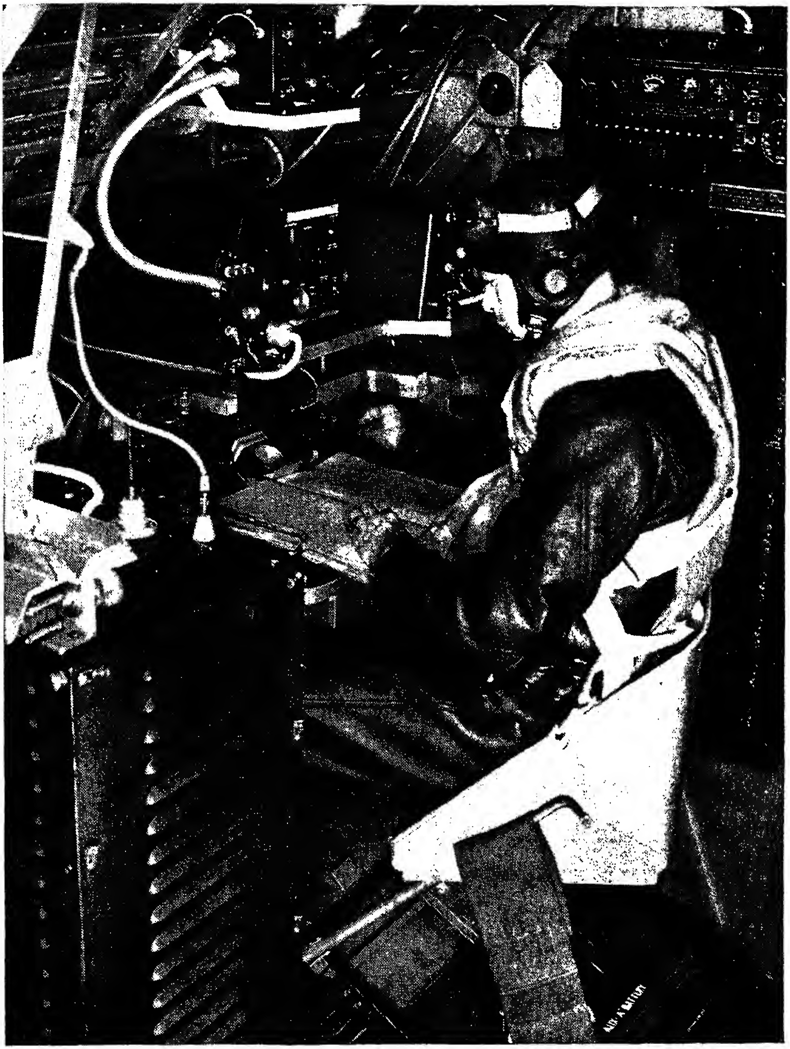
Weather Broadcast	*Time*
Seattle: Seattle terminal forecast, Seattle upper air	20′
Seattle to Spokane	43′
Vancouver, British Columbia, to Portland	48′

Forty-three minutes after every hour the pilot gets a fresh report on the weather between Seattle and Spokane.

A pilot with two-way radio can request weather information at any time from stations on his course. He receives, as part of the prescribed routine exchange of messages in traffic control, further weather data. When entering or leaving an airport the plane must first contact the control tower for permission and direction. On receiving permission to land, the pilot is given the altitude of the field, ceiling height, visibility, altimeter setting, wind direction, and velocity.

Where there is no traffic control, the pilot may have to judge wind direction and velocity from the wind sock flying over the hangar. Visibility and ceiling may be unimportant, if weather is clear. Otherwise the pilot may depend on whatever landmarks or lights are visible and on his altimeter.

The altimeter is an essential instrument but it can only be used when corrected for atmospheric pressure, which continually varies with weather conditions. This is an important correction. In planning a flight, the avigator secures the altimeter corrections for all major points along his course for five hours or so in advance. When landing at a traffic-controlled terminal, this altimeter setting is given the pilot by radio as part of his landing directions. Otherwise the pilot must use the figure obtained earlier from the weather report. If the correction is accurately used, the altimeter of the plane can be set to register the true height of the plane above the ground. It will read zero when the plane has landed.



Official U. S. Navy Photograph

WITH RADIO THE PILOT CAN OBTAIN THE LATEST WEATHER INFORMATION WHILE IN THE AIR

The pilot must use weather data as he uses his instruments and controls. This knowledge is as much a part of the plane as the rudder or the compass. In avigation, weather data are as important as charts. The constant improvements that are taking place serve to increase the number of flying days per year. Figures from the United States Weather Bureau show this improvement. In 1935 there was one accident due to weather for every five and a half million miles of air travel. Certainly a small enough proportion. But by 1940 the ratio had dropped to one accident in fifteen and a half million miles of flight. This includes all accidents attributed to the weather. There has been only one fatal accident in fifty-four million miles. Unusually mild or severe winters will, of course, make a difference and no one can definitely state how much of the improvement is due to the work of the Weather Bureau or how much is due to the pilots or plane manufacturers. The important thing is that the weather is gradually being conquered.

Improved forecasts and the use of new and better instruments are, in effect, banishing fog, clouds, and darkness. Pilots realize that the forces of the weather are occasionally so strong that air traffic must cease. But radio and flight instruments are making the factors of ceiling and visibility of less importance. It may be some time till these can be completely ignored—but the job is well under way. It won't be long till the pilot will merely shrug his shoulders instead of going into a cold sweat when the radio from the airport below reports "Visibility zero; ceiling zero."

11

INSTRUMENTS OF AVIGATION

YOU HAVE a good idea how easy avigation would be *if*—if the earth did not rotate; if only planetary circulation prevailed; if charts accurately portrayed the spherical surface of the globe. But scientists do not waste time in lamentation over what might be. They try to meet the situation that exists. Inventions have gone far toward overcoming the imperfections of this world. Of all the imperfections that create problems in avigation, the imperfections of the human body are first and foremost.

Conceive the human body as a machine—a complex engine producing heat, motion, and sound. Our special senses might be compared to cameras, microphones, scales, barometers, etc. But our senses are all imperfect—so much so that the avigator cannot always count on them to tell him his position, direction, or velocity. Our eyes, ears, and pressure senses often fool our mind. We *can* count on mechanical instruments properly used.

An inexperienced pilot flying through the overcast may look at his instruments and feel they are in error. His senses tell him he is upright but the bank and turn indicator shows the plane in a steep bank. The experienced pilot trusts the instru-

ments and will correct his bank before he finds the plane going into a spin. There is the actual case of a pilot flying a light plane in heavy clouds. The plane was tossed about by rough air and a particularly heavy gust turned it completely over. The pilot continued right along—it took his senses some time to tell him he was upside down when all he could see around him was cloud.

All flying nowadays is instrument flying. Even in a contact flight the pilot has the aid of instruments. Instruments are increasing in importance for all kinds of flying. They cannot yet take the place of the pilot but they certainly do help in making a flight safer and more efficient.

You are probably familiar with many of the instruments carried in planes. A few have already been mentioned in this book and the compass has been treated in some detail. Of course, the purpose of the majority of a plane's instruments is to inform the pilot of the condition of the plane: how fast the motors are turning, how hot the oil is, how much fuel remains in the tanks. Dials tell when the landing gear is retracted, report on the oil pressure, propeller pitch, current being used, and if the engines are synchronized. The dials and controls on the instrument board of a large transport number approximately one hundred. Basic instruments are duplicated as a safety factor and for the convenience of the co-pilot. In addition, the plane carries avigation instruments that help the pilot establish his position, direction, and speed.

It is to these instruments that we will give our attention,

though in a sense every instrument on the plane is an avigation instrument if it is essential in controlling the plane and getting it to its destination. First there is at least a magnetic compass and perhaps an aperiodic compass, too. Then, depending on the plane, you may find one or more standard or sensitive altimeters. Next comes the primary flight group of instruments—the climb indicator, bank and turn indicator, and air speed indicator. Large planes may have an accelerometer, directional gyro, gyro horizon or artificial horizon, and possibly an automatic pilot. An accurate clock is essential; a thermometer useful. There is a whole array of radio devices and more specialized instruments used with celestial navigation.

To pick out *the* most essential instrument for avigation is quite impossible. Civil Air Regulations require that each plane have an altimeter and an air speed indicator (besides engine instruments). If the plane goes farther than one hundred miles from its base, the rules require that a compass be carried. For instrument flying a bank and turn indicator must be installed; also a more sensitive altimeter, a clock, and a rate of climb indicator. Airliners carry still more instruments. Finally there are refined specialized navigation instruments used only for special flights and those that are still in the experimental stage.

The total number of instruments carried on a plane is not a matter of first importance. The thing to consider is the use of instruments to meet the specific needs of the pilot, his plane, and his flying problems. Some of the instruments you will read about in the following pages are never used and would be out of

place in a small private plane. Some are too bulky, too expensive, and require too much attention from the amateur pilot, but they are absolutely essential in an airliner. Some of these newer instruments may become very important in the future as they are modified and perfected.

Though avigation instruments help the pilot in many different ways, the instruments themselves have certain similarities of operation that make it possible to speak of two principal groups of instruments—the pressure instruments and the gyroscopic instruments.

The pressure instruments are those depending directly or indirectly on the pressure of the air for their operation. Of these, the altimeter is best known and most important. The altimeter of a plane is one form of barometer. A barometer is a balance instrument that directly measures the pressure of the air. Since pressure decreases with an increase in altitude, the barometer can be calibrated directly in feet, and used to measure height directly.

There are two types of barometers—the mercurial and the aneroid—and both act on the same principle. The mercurial barometer, which consists of a reservoir of mercury and a glass tube sealed at the top, is acted upon by air pressure supporting a column of mercury about 30 inches high at sea level. At a 1,000 foot elevation, the air pressure will support a column about an inch less. The height of the mercury will continue to drop at a rate approximating one inch per thousand feet of elevation at low altitudes. Higher up, the rate of fall will gradually

diminish.

In the aneroid barometer there is no mercury. Instead the air presses on a waferlike metallic chamber from which air has been withdrawn. The springlike nature of the corrugated chamber walls prevents the collapse of the cell under the pressure of the air. When the air pressure changes, the walls of the chamber respond—giving slightly as the pressure increases and bulging a bit when there is a decrease. These changes in the cell are very small but by means of a system of levers the movement is magnified. A chain and spring mechanism connects to a moving hand indicating pressure or altitude on the aneroid dial.

The real difference between the aneroid barometer and the altimeter is the scale of the dial. The barometer is calibrated in inches of mercury and the needle moves down the scale as the air pressure decreases. The altimeter is marked directly in feet, and is calibrated in the reverse so that the needle rises as the pressure falls with altitude. Changes of temperature and pressure with the weather cause the altimeter to give incorrect readings. In avigation, the altimeter is frequently corrected in flight so that the instrument dial gives a more true indication of the height of the plane above sea level. The pilot gets the data for the correction via radio. A knob on the altimeter dial permits the adjustment to be made rapidly.

The air speed indicator makes use of differences in air pressure to show the forward motion of a plane. The principle is again simple. The pressure of the air against any object moving through it increases with the speed. You can easily demon-

strate for yourself by holding your hand out of the window of a moving car. If the driver steps on the gas, you can feel the pressure change as the car picks up speed. Since the pressure is proportional to the speed, measurement becomes a relatively simple task.

The air speed indicator is a device that permits air to rush through a tube connected to the plane and press against the walls of a metallic cell, similar to that in an aneroid barometer. The effect is magnified by levers and shows on the instrument dial. However, such an instrument would also be affected by any changes in the air pressure and would function as a barometer. Hence it would be misleading as a speed indicator. To overcome this difficulty, *two* air tubes are used. The first is open at the end and receives the full impact of the air as the plane plunges through it. The second tube is sealed at the end but along the side are small holes through which air may enter. The pressure of air entering through these side holes varies with altitude and temperature, but not with the speed of the plane, as the holes do not open in the direction in which the plane is moving. This second tube (*the static tube*) leads to an air-tight instrument chamber and the first tube (*the pitot tube*) leads to the interior of the metallic pressure cell.

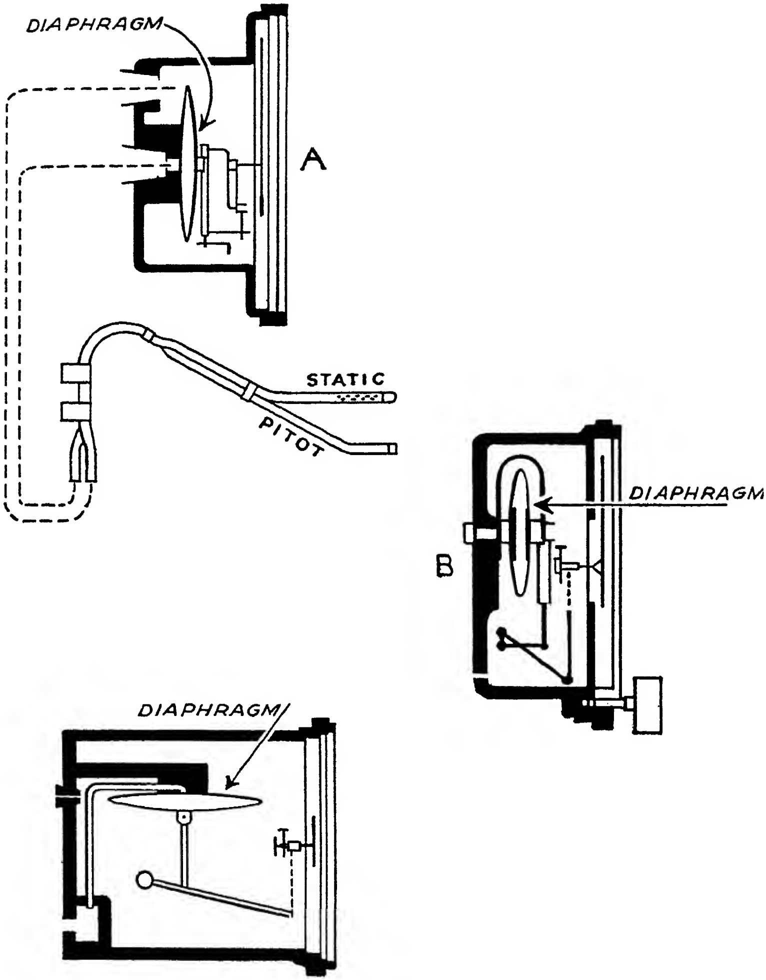
By the use of the two tubes, the instrument actually measures difference of pressure between still air and air acting against the moving plane. This difference is due to air speed of the plane. The air speed indicator in actual use is a delicate precision instrument. It includes a heating device to keep ice from

forming on the static and pitot tubes.

Check back over the operation of the air speed indicator and you will see that there are sources of error inherent in the nature of the air itself. Just imagine two planes going forward at exactly the same speed—but one plane 10,000 feet above the other. Would the air speed indicators read the same? Unfortunately, no. The upper air being less dense would not produce as much pressure even though the speeds were the same. A similar discrepancy would be found if a plane were traveling through warm air. The warm air is expanded and is also less dense.

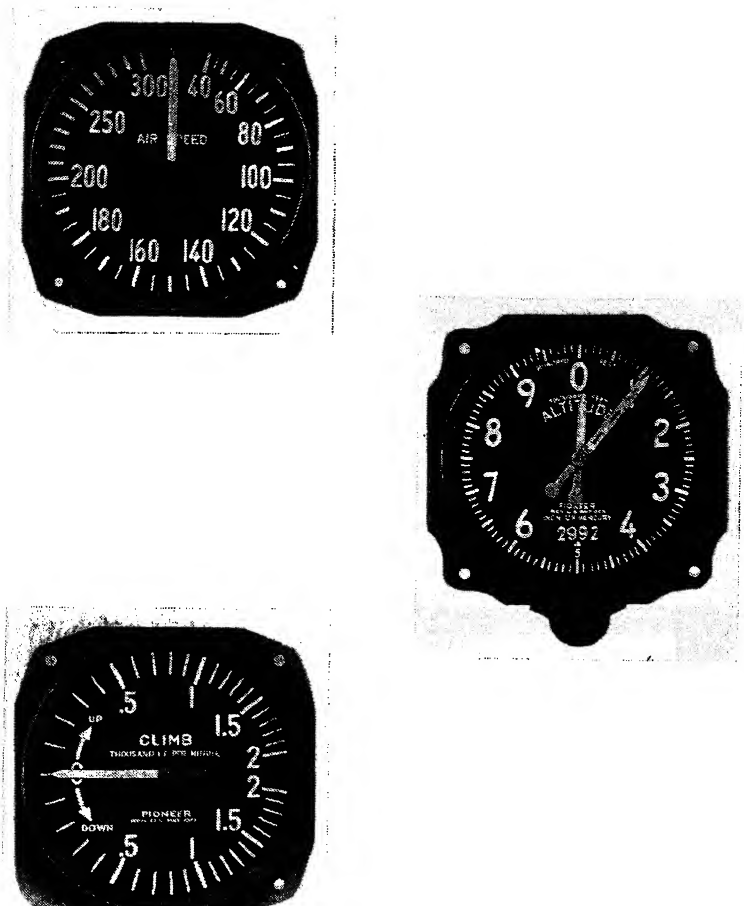
No correction for these factors can be made in the instrument so the avigator has to make his own corrections. Generally speaking, the instrument reads about 2% low for each thousand feet in altitude. If the dial read 100 miles per hour when the plane was at 10,000 feet, that reading would be 20% low and the true air speed would be about 120 miles per hour. For more accurate corrections the pilot has tables that give the true speed when the altitude, temperature, and indicated speed are found on the graph.

The air speed is not only important in itself but without it the pilot cannot compute his ground speed. Furthermore, the pilot can use the air speed indicator to determine his best climbing angle. The air speed will drop rapidly on too steep a climb because the plane is slowing down to a point where it will stall. The pilot who knows his usual air speed at various engine speeds can use these facts in keeping his flight level when visibility is poor. A change from level flight at a given engine



A	B	C
AIR SPEED INDICATOR	ALTIMETER	CLIMB INDICATOR

ALL OPERATE ON THE PRINCIPLE OF AIR PRESSURE



Courtesy of Bendix Aviation Corporation

DIALS OF AIR SPEED INDICATOR, ALTIMETER, AND CLIMB INDICATOR

speed will increase air speed if the plane is nosing down and decrease it when the nose of the plane is up.

A more accurate method of determining ascending or descending flight is by the climb indicator. This instrument, too, operates on the pressure system. The climb indicator contains a metallic cell or diaphragm like that in the altimeter. This diaphragm is not evacuated but is connected to the outside air by means of a large static tube. The diaphragm is mounted in a chamber that opens through a much smaller vent tube. The opening through this capillary tube is about the diameter of a hair and, while it permits air to enter and leave the chamber, the transfer of the air is of necessity slow because of the small size of the opening. Changes in air pressure immediately affect the air in the diaphragm but only gradually affect the air in the chamber.

When the plane is in level flight the pressure inside the climb indicator chamber and inside the diaphragm is the same. It is in exact balance. But now the plane begins to climb; as it does so the surrounding air becomes less dense and the pressure drops. So does the pressure inside the diaphragm with its large opening. However, the air in the chamber does not change so rapidly. The capillary tube slows up its motion. As long as the plane keeps climbing, the air in the chamber is always at a slightly higher pressure than that in the diaphragm. When the plane levels off, the pressures equalize. When the plane dives, the reverse occurs. Pressure in the climb indicator diaphragm increases as the plane tilts toward the earth. But as long as the plane is diving, the pressure within the chamber will be a bit

less, because of the slower adjustment.

This difference in pressure when the plane is climbing or diving operates a lever and chain action that in turn moves the needle across the dial of the climb indicator. The dial is calibrated in plus and minus directions in rates of thousands of feet of vertical change per minute.

The climb indicator has a double purpose. First and obviously, it tells the pilot if he is climbing or diving and how fast. Secondly, and perhaps more important, it enables the pilot to maintain level flight in overcast or at night. Used with the altimeter and air speed indicator the pilot has a good check on the vertical component of his flight.

The instruments just mentioned operate directly as a result of pressure of the air and changes of that pressure. By these ingenious devices the air itself tells the pilot his height, speed, and rate of climb.

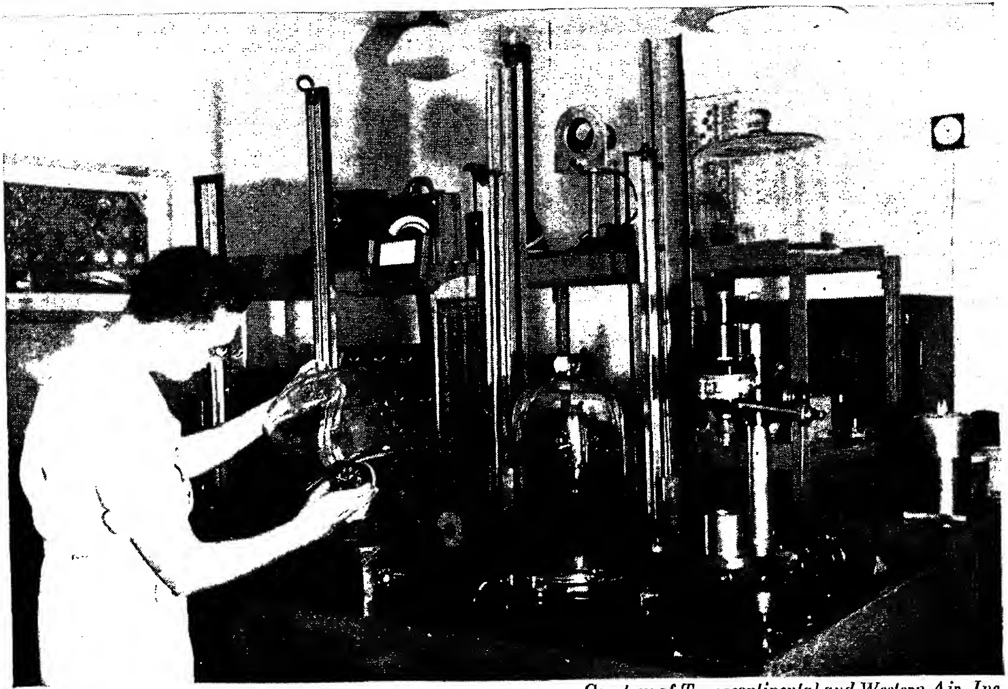
Two other devices should be in this chapter. They do not operate by air pressure but by an even more universal and penetrating force—gravity.

The accelerometer (also known as the load factor meter) measures changes in the vertical velocity of a plane. This may seem an odd thing to measure, but it is important because of the way the force of gravity acts on a plane. When a plane dives or if it is falling, it does not descend at a constant rate of speed. The pull of gravity on a falling (or diving) object is such that the rate of fall increases with every second. The first second an object falls 16 feet, the second, 64 feet, the third,

144 feet—its rate of fall is constantly increasing. The pressure and, hence, strain on the plane depends on its weight, structure, and speed. In a dive, speed is rapidly increasing up to a certain point. When the plane is coming out at the end of a long dive, the pull on the wings and body may be five or six times the normal pull of gravity.

Inside the accelerometer is a pivoted weight held in a horizontal position by springs. In level flight the dial indicates 1 g. —i.e., the plane is under the normal pull of gravity. Coming out of a dive the velocity is changing fast from a high downward velocity to an almost equal upward velocity. This is, in effect, a tug of war against gravity. The increased pull on the pivoted weight indicates on the dial the force of the downward pull in units expressed as multiples of the normal pull of gravity. This accelerometer dial is the one the test pilot watches so carefully the instant his plane is coming out of a power dive.

Less spectacular, though more important, is the bank indicator that indicates the lateral or sidewise position of the ship. The bank indicator is merely a curved glass tube containing a small steel ball and a liquid to dampen its movement. In level flight the ball is at the lowest position in the curved tube. If the pilot is turning and the turn is correctly banked, the centrifugal force of the plane balances the down pull of gravity and keeps the ball in the middle of the curved tube, even though the plane is now tilted at an angle. But if the plane is banked too little or too much, centrifugal force will be greater or less than gravity. Then the ball will roll in the tube in the direction of



Courtesy of Transcontinental and Western Air, Inc.

ALL PLANE INSTRUMENTS MUST BE CALIBRATED AND CHECKED. BY EXHAUSTING THE AIR UNDER THE JAR, THIS ALTIMETER CAN BE TESTED UNDER CONDITIONS SIMILAR TO THOSE FOUND IN FLYING

the low or high wing of the plane, depending on whether gravity or centrifugal force is stronger at that instant. The plane may skid or side-slip under such conditions unless the pilot uses the ailerons to correct the plane's angle. In the overcast it is difficult to judge the bank of a plane. This simple instrument, therefore, becomes an important guide to the pilot.

The bank indicator is usually incorporated with a turn indicator in a combination instrument of greater value to the pilot than either one alone. The bank and turn indicator is just two instruments mounted in the same housing. This is easily done, as the bank indicator takes up very little room. The turn indicator brings us to an entirely different group of avigation instruments that were developed from the common gyroscopic top that children often use as a toy.

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GYROSCOPIC INSTRUMENTS

NEARLY everyone has seen or played with a gyroscope at some time or another. The simple toy gyroscope is a metal wheel mounted on pivots in a wire framework. Spun by a string, the wheel performs all kinds of acrobatic tricks as long as it keeps spinning. As the wheel turns, the framework turns slowly, too. The simple instrument acts in this definite way because of its speed of rotation. The properties of the gyroscope are such that a number of essential avigation instruments are based on the action of this fast-spinning wheel.

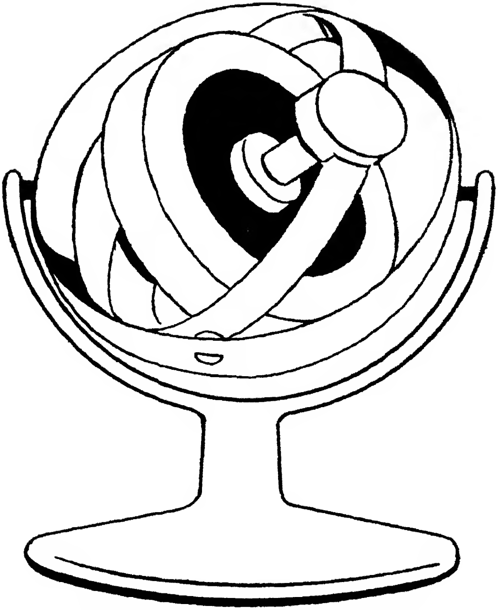
Several forms of gyroscopes are used in planes. Each gyroscopic instrument contains a wheel with fins or vanes. A nozzle directs a strong stream of air against the fins, causing the wheel to spin rapidly—at speeds up to 12,000 revolutions per minute. The gyroscope does not display its essential properties unless this high speed is maintained. Not compressed air, but air under normal pressure spins the gyroscope. This is effectively done by exhausting the air from the gyroscope chamber so the normal air pressure outside is many times greater. Under these conditions the difference in pressures causes the air to rush in through

the nozzle at high speed. The fact that the air in the chamber is partly exhausted reduces the friction in the chamber and increases the speed of the gyroscope wheel.

Air is removed from the gyroscope chamber by means of a device called a *venturi tube.* The venturi tube is so mounted on the plane that air from the slip stream rushes through it rapidly. This rush of air through the tube's restricted opening produces a decrease in pressure within the venturi tube. A small flexible pipe leads from the venturi chamber to the instrument and keeps the air within it at reduced pressure. The venturi tube is often mounted near the exhaust pipe from the motor to prevent icing in the tube. This rush of air draws the air from the venturi chamber through a small side tube that connects with the gyroscopic instrument. On larger planes where several gyroscope instruments are used, the decreased pressure in the chamber is obtained by an engine-operated vacuum pump. Should the pump go wrong, the pilot can throw a valve and connect the instruments to the venturi tubes for emergency use.

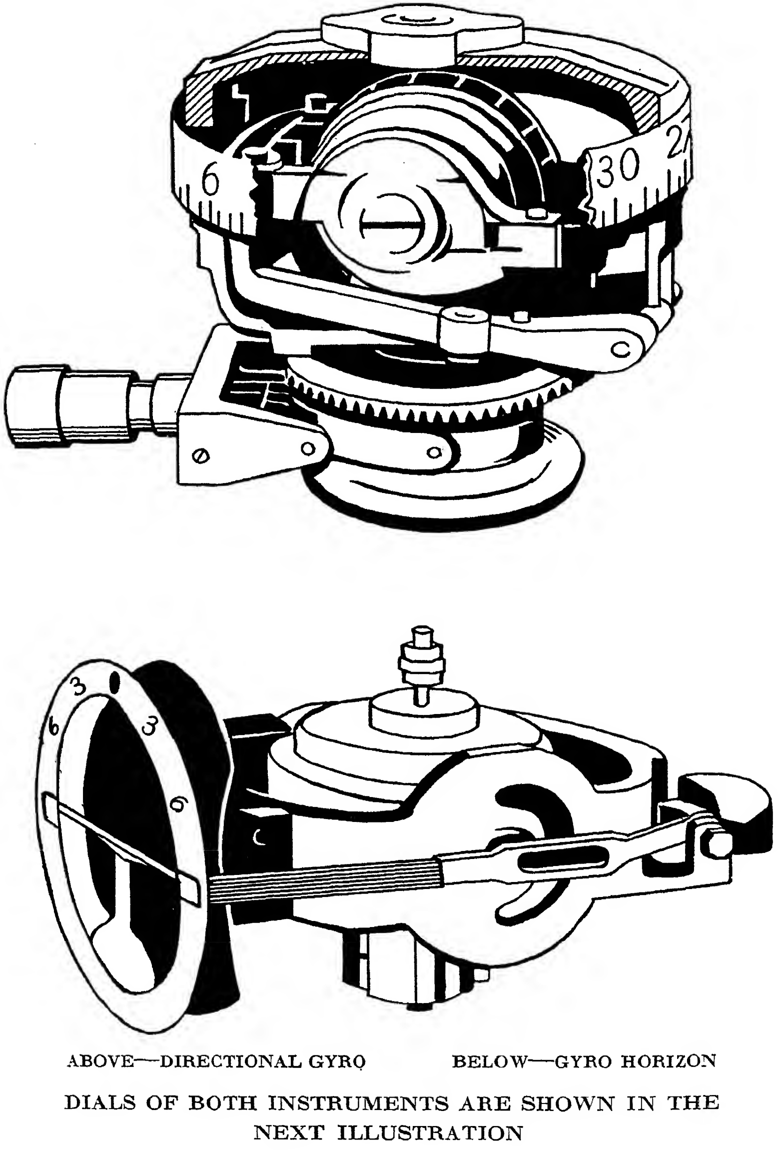
Two basic properties of the gyroscope make it valuable in avigation. First, a spinning gyroscope tends to rotate in a definite plane and resists any force that disturbs it. This, in brief, is the principle of *rigidity* or inertia. Second, when the spinning gyroscope is rotated around some axis (as when a plane is making a turn) it tends to turn itself so that its axis lines up with the axis about which it is rotated. This is the principle of *precession* on which the turn indicator operates.

The bank and turn indicator contains both the simple gravi-



THE GYROSCOPE MOUNTED SO THAT IT CAN SWING IN ALL DIRECTIONS IS THE INSTRUMENT FROM WHICH SEVERAL NAVIGATION AIDS HAVE BEEN DEVELOPED

tational device that indicates bank and the more complicated gyroscopic instrument that shows turns. The turn indicator is probably the more important, as the avigator uses it to supplement his compass, which always errs when the plane is turning. The gyroscope of the turn indicator revolves in a vertical path —that is, its axis is horizontal and parallel to the wings of the



ABOVE—DIRECTIONAL GYRO BELOW—GYRO HORIZON

DIALS OF BOTH INSTRUMENTS ARE SHOWN IN THE NEXT ILLUSTRATION

plane. The axis is pivoted in a framework which is itself mounted on pivots parallel to the fore and aft (longitudinal) axis of the plane. The gyroscope can spin on its axis and rotate on the framework axis. But the framework axis is anchored to a spring that resists rotation and brings the framework back to position.

When the plane turns, because of precession the gyroscope tilts to one side about the longitudinal axis of the gyro frame. This tilting of the gyro is proportional to the sharpness of the turn of the plane. A mechanical connection moves the hand across the dial of the turn indicator. When the plane has stopped turning, the effect of precession ceases and the hand returns to the center of the dial. The dial of the turn indicator is marked with a point on either side—left and right—of the center mark. When the hand reaches that point the plane is turning at a rate that will produce a complete change in direction (180° turn) in one minute.

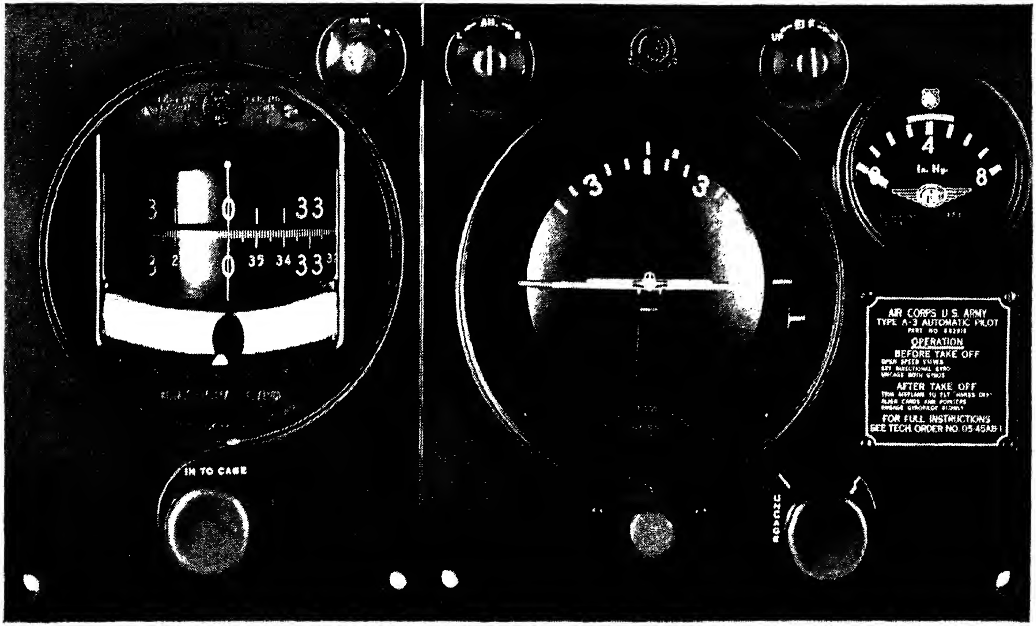
The directional gyro performs all the functions of the turn indicator and more. It is sometimes manufactured with a bank indicator on the same dial giving the combination of bank and directional gyro instead of the better known bank and turn instrument. The directional gyro operates in the same mechanical way as the turn indicator except that the gyroscope is mounted differently and its action depends on the rigidity of the gyroscope—the instrument's resistance to change.

The directional gyro is so mounted that it is free to turn in any direction. The pivots provide a universal mounting, so

the case in which the gyroscope is mounted can be moved in any direction, while the wheel itself continues to spin steadily in its vertical path in a fixed direction. Around the frame is a horizontal circular dial marked in degrees, which the pilot watches as he does his compass dial. In action the directional gyro stays put while the plane turns around it. The amount of turn is easily seen as the lubber line on the instrument board moves past the dial of the gyrocompass.

In use, the plane is flown on a level course and the directional gyro is set (by means of a hand-controlled knob) till it agrees with the compass. Sometimes, for convenience, the directional gyro is set at zero for the course—thus making it easier to watch. A pilot may have determined his compass course to be 240°. He gets on the course. Then he either sets his directional gyro to 240° or to 0°. In either case he can now tell accurately and quickly if he is turning off course. The compass may lag or oscillate on turns but the directional gyro quickly indicates the amount the plane has turned off course.

The directional gyro, because of precession, slowly changes its direction so it becomes necessary during flight to reset the instrument every fifteen minutes or so. If this is done, the instrument makes it easier for the pilot to stay on his course than if the compass were used alone. Together the directional gyro and compass are a dependable pair. Recently experiments have been under way to combine the two instruments and develop a directional gyro that is constantly and automatically reset by the magnetic compass. When this instrument is



Courtesy of Sperry Gyroscope Co., Inc.

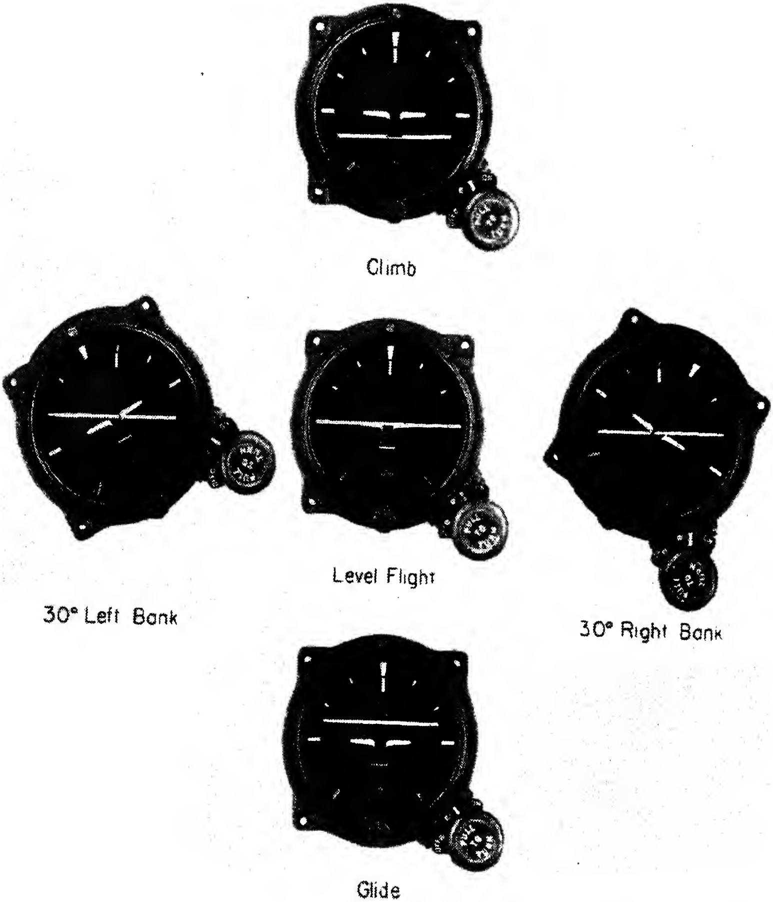
THE AUTOMATIC PILOT COMBINES THE DIRECTIONAL GYRO AND GYRO HORIZON WITH A MECHANISM THAT REGULATES THE CONTROLLING SURFACES OF THE PLANE

perfected the pilot will have an almost perfect indicator of direction.

One further modification of the gyroscope is the artificial horizon, an instrument that provides the avigator with a horizon when the natural one is obscured by clouds or darkness. When the horizon is visible, the pilot can use it as a line of reference and can determine whether his plane is nosing up or down or whether it is banking left or right. Cut off from a horizon as a line of reference, a pilot's senses do not serve as well. And it is often humanly impossible to judge from within the cockpit if the plane is climbing or banking.

The artificial horizon gives the pilot a line of reference. Here the gyro is mounted so it spins horizontally on a vertical axis. Instead of a lubber line, a miniature plane outline is mounted in front of the instrument. The moving dial attached to the gyroscope has a horizontal white line and a pointer, indicating degrees of bank. The spinning gyroscope holds the artificial horizon line parallel to the earth. When the plane is in level flight, the miniature plane on the dial sets exactly on the horizontal line. As the plane climbs, the line drops and the miniature model rises above the horizontal. On a glide, it drops below. The indicator banks right and left as the plane does. Because of its universal mounting, the gyroscope can indicate any combination of these movements such as a climb with a 30° left bank or 45° right bank on level flight.

All the gyroscopic instruments are delicately balanced and constructed. They must be protected from shock and from very



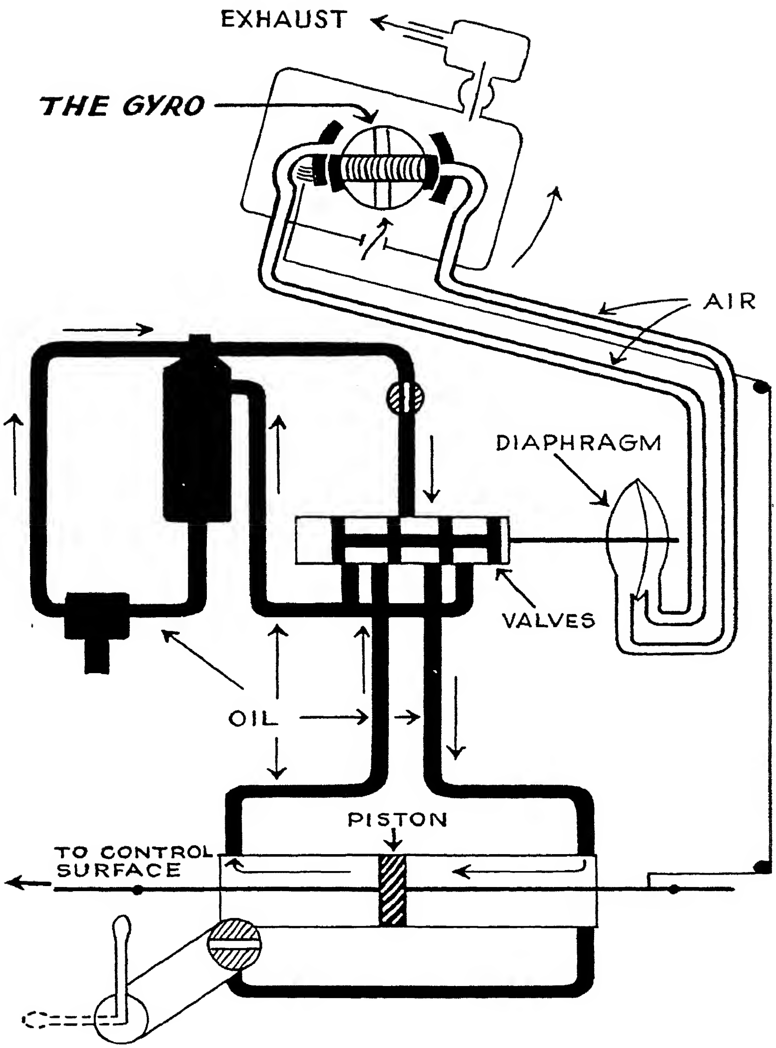
Courtesy of Sperry Gyroscope Co., Inc.

THE GYRO HORIZON SHOWS THE PILOT THE POSITION OF HIS PLANE IN RELATION TO A TRUE HORIZONTAL LINE

sudden movement. A very steep dive or bank would throw the artificial horizon out so that it might be twenty minutes before it returned to normal. To prevent accidents and eliminate difficulties of this kind, the pilot may "cage" each gyro instrument (except the turn indicator) when he is going into an unusual maneuver or into acrobatic flying. This action puts a brake on the gyro framework, and once the plane has returned to level flight the instruments can be released and will immediately give normal readings.

The last word in flying instruments is the automatic pilot which combines the directional gyro, the artificial horizon, and an altitude control with a mechanism that permits each instrument to control directly the steering surfaces of the plane. With this instrument the pilot can set and maintain any course with no more attention than is needed to reset the directional gyro. Changes in course are easily made. The course need not be level. It may include a climb, glide, turn, or any combination of these.

An air take-off on either side of the spinning gyro moves a sensitive diaphragm that reacts to differences in pressure like the cell in the climb indicator. Any departure of the plane from the course set by the pilot is translated into differences in air pressure on either side of the balanced diaphragm. This in turn connects to an oil valve controlling oil under pressure. The oil flows into a cylinder and by hydraulic pressure on the piston moves the rudder, elevator, and ailerons of the plane attached to it by control cables.



THE AUTOMATIC GYRO PILOT CONTROLS THE PLANE BY MEANS OF A DIAPHRAGM THAT REGULATES THE PRESSURE OF OIL AGAINST A PISTON

The directional gyro connects to the rudder to give directional control to the plane. The pilot can usually count on staying within 3° of his course for half an hour before a gyro adjustment is necessary. The artificial horizon controls climb and glide, roll and bank. Connections to the elevators and ailerons take care of the mechanics of this phase of flight. A vacuum gauge mounted with the other instruments shows if there is sufficient vacuum to operate the gyroscope wheels at the proper speed.

This rather complicated mechanism is only used on large transport planes. It is, of course, expensive and a super-refinement. But when the pilot has heavy responsibilities (What pilot of a transport does not?) such assistance is far from being an extravagance. The automatic pilot is even more sensitive to changes of direction than its human master. It reacts to differences as small as 1/20° and makes the proper adjustments. Once the pilot takes off, he can set his automatic assistant to a climb that will bring the plane up to the correct flying altitude—he can then set it for level flight on a given course. Occasionally the directional gyro will have to be reset and the course changed. Nearing the destination the pilot can set the plane at a glide till he is ready to take over for the landing. In an emergency the pilot can take over immediately. As soon as he pulls the stick or steps on the rudder pedals a by-pass valve disconnects the automatic pilot.

It would be erroneous to picture the pilot of a transport as idle, with a robot doing all his work. Helpful as the automatic

Official U. S. Navy Photograph

AS PART OF THEIR TRAINING ALL PILOTS LEARN THE THEORY AND OPERATION OF GYROSCOPIC NAVIGATION AIDS

pilot is, it can do little more than give the pilot temporary relief from a strenuous task so he can focus his attention on his motors, his radio contacts, or on his avigation.

The remaining navigation instruments on a plane's panel might well be set down as miscellaneous. They are few in number and differ widely in purpose. With two of these you are already familiar: the magnetic compass (of several types) and the drift indicator—though the latter is not on the instrument panel at all but is mounted on the floor, so the pilot can look through the instrument and measure the angle of drift on objects as they stream past below.

Of the remaining instruments used in avigation, the clock is conspicuously important. Time and distance mean the same thing to a pilot; 500 miles or four hours' flight express the same idea. In dead reckoning, in instrument flying, and in just keeping on any planned schedule, correct time is important. Aircraft clocks must be nearly as accurate as those special timepieces used on shipboard—the chronometers. They are subject to shock and continual vibration that increases the wear on a sensitive instrument. With the help of radio time signals, the pilot can check his time accurately and keep his clock adjusted. The clock has still further use in navigation—when it is necessary to determine position by the sun or stars. That use will be explained in a later chapter.

On the panel may be a thermometer connected to a unit that measures the temperature of the free air at a point outside the fuselage. This temperature may be used to get correct readings

on the climb indicator. It may also be used by the pilot with his weather data to guard against flying through cold moist air that causes icing.

The other instruments on the panel are those directly measuring the conditions of the motors, speed of rotation, temperature, oil pressure, fuel, manifold pressure, and the like. All the instruments, especially those used in avigation, must be given the strictest care. They must be periodically inspected, tested and kept in perfect working order. A pilot depends too much on his instruments to take any chances.

There are other instruments besides those you have read about in these chapters so far. The instruments mentioned in the last two chapters are mechanical aids to a pilot. With these the trained pilot can fly where and when he wishes, weather permitting. But most aviation is not dependent on the whim of the pilot and only a small part is concerned with flights of exploration and discovery where the pilot is on his own. Nowadays most planes stick to the major skyways as automobiles hug the main roads below. The main arteries of air traffic are as easy to recognize as the Lincoln Highway or the Merritt Parkway.

To keep on the skyways, to keep on schedule, and to keep flying safely, the pilot uses one further set of instruments to insure constant touch with airports, beacons, and stations. With the aid of radio the pilot can literally call on hundreds of assistants to help him in his flight. The radio instruments in their various forms are of increasing importance in flying. The pilot,

constantly using the radio, never has a chance to listen to his favorite program. The way he uses radio as an aid to avigation you will presently find out.

13

RADIO NAVIGATION

RADIO must be put with the top flight navigation instruments. If radio instruments aren't the most important yet, they soon will be—in the opinion of aviation experts. Certainly radio has achieved wonders. The pilot is no longer isolated, dependent only on his own knowledge and skill. With radio aids he can call in assistance, secure advice, information, and aid in an emergency.

While receivers on planes can pick up and use commercial broadcasts as an aid to avigation, most aeronautical radio work is done on short wave. With all radio waves, the shorter the wave, the higher the frequency or rate at which waves are sent out, and the longer the wave length the lower the frequency. So that talking about short wave and high frequency amounts to the same thing. The programs you listen to daily are broadcast on a frequency band somewhere between 550 and 1,600 kilocycles—WMCA at 570, WABC at 880, and WQXR at 1,560. Since kilo is the prefix meaning thousand, these stations broadcast at frequencies of from 550,000 to 1,600,000 waves per second.

Several wave bands have been assigned to aviation, ranging in groups from 200 kilocycles up to 143,000 kilocycles. The

frequencies of these very short waves are often given in megacycles (1,000,000 cycles) instead of kilocycles (1,000 cycles) to avoid the use of large numbers. 143,000 kilocycles or 143 megacycles express the same frequency. Till recently the 200-400 kilocycle band was used for radio range stations. It is now being changed over to an ultra-high frequency band where static and other disturbances will be decidedly less. As a result of government research, more high frequency wave bands will be used with planes—resulting in improved radio reception in the airway channels.

Government licenses for airway radio fall into a number of groups—each license for a specific purpose. The transmitters in planes form one group of mobile stations. Airline planes have at least two assigned frequencies: a high frequency band for daylight use, a lower frequency for night. The short waves carry farther with less interference during daylight. Other wave bands are assigned to private planes or planes not flying on schedule. Then another license is available for fixed stations located at airports, primarily for communication with mobile stations on the airways.

Of the ground stations the most common ones are those located at airport control towers for traffic control of planes in or near the airport. Such stations have operated at a frequency of 278 kilocycles but are being changed over into ultra-high frequency stations of about 130,000 kilocycles (130 megacycles). These are low-powered stations (15 watt), as their function is to contact planes in the area immediately surrounding the airport.

Aeronautical stations and the aeronautical point-to-point stations keep in contact with planes during flight. The major airlines co-operate in maintaining a network of ground stations and in sharing wave bands, so there is neither confusion nor complication in the use of aeronautical radio.

A number of related services are tied in with radio and aviation. There is the teletype system used in routing planes along the airways and for transmitting weather reports. Telephone circuits tie in also, making it possible to reach a person on a transport plane by phone, though air regulations do not permit this use. The radio itself is used in two forms: radiophone for most messages and short distance contacts; and radiotelegraph, in code, for longer distance, for sending at times of atmospheric disturbance, and for use in the automatic radio devices.

Primarily, radio is a method of communication. Radio communication on the airways is controlled by strict rules. It is entirely a matter of business—with safety as the keynote. Every plane in which instrument flying is permitted is equipped with both a receiver and transmitter with a range of over 100 miles. The pilot's radio aids are in constant use every minute he is in the air. Traffic control regulations require that the pilot report by radio as he passes each checking point on his flight plan. A PX (position report) message goes out over the teletype as the pilot leaves the airport, giving his plane number, destination, and time of taking off. As the pilot passes over a beacon and reports, a passing-over message is sent along the line so that the position of the plane is followed from its departure

till it lands.

The rigid form of radio messages is determined by explicit rules that tell just how a message shall begin, in what order facts are given, and how and when messages end. You have probably heard airplane radio messages either in the movies or directly if your radio has the proper short wave bands. There is no place on the airway radio for personal messages or for gossip. From the first "Calling" and "Go ahead" to the last "O.K." the message is completely controlled to give and get information quickly, systematically, and without error.

Most radio messages are strictly routine: messages giving position, weather conditions, flight instructions, etc. But in an emergency these routine messages are temporarily set aside and the entire air is kept clear except for the stations in immediate contact with the distressed plane. Over the air routes the spoken word MAYDAY repeated three times is the equivalent of an S O S at sea. MAYDAY is the English form and spelling of the French M'AIDER—help me—as logical a distress signal as could be. It is a distress signal indicating that the plane is in immediate peril. When this signal is sent with the plane's identification and location, every effort is made to render assistance. If the danger is not as imminent, the urgency signal PAN is sent. This is taken from the French word *panne,* meaning a breakdown. This secures priority over other messages and requires that anyone listening continue to listen till the end of the message. There is also a safety signal, the word SECURITY repeated three times. This is used as a prefix to messages involving the safety

Official Photograph, U. S. Army Air Forces

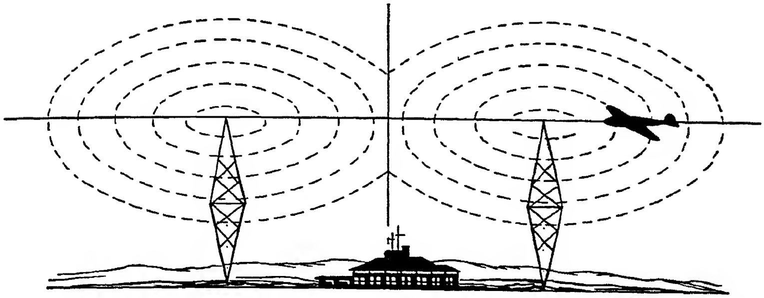
BESIDE THE RADIO BEAM, COMMUNICATION BY RADIO PHONE AND CODE KEEPS THE PILOT IN CONSTANT TOUCH WITH GROUND STATIONS

of the plane and of the passengers, though there may be no immediate danger. Safety messages rank third in priority.

These routine and emergency messages are certainly aids to avigation. They make flying safer and protect life and property. Yet they are only indirect aids to the immediate problem of getting a plane to its destination. Radio can be and is of much more direct help. The direct radio aids to the pilot show the ingenuity of scientists and inventors who have adapted the basic methods of radio communication to new and essential tasks in air navigation.

Mile after mile of invisible signposts cover the United States and point out the air routes to the pilot. The system of the radio range extends across the country to form a series of east-west and north-south routes. There are nearly 300 radio range stations sending out directive radio signals that the avigator can follow. The radio range system is so basically important in air navigation that you ought to be thoroughly familiar with the way it works.

Several types of antennae are used in radio broadcast. When a single vertical antenna is used, the radio waves are sent out with equal intensity in all directions, somewhat like the ripples from a pebble when it is dropped in still water. Two vertical antennae, properly placed, produce a different type of wave pattern. In the plane of the two antennae, the radio waves are strongest. At right angles to the plane of the two antennae, the strength of the waves is at a minimum. Instead of a circular pattern the wave pattern might be pictured in the form of a



A RADIO SIGNAL SENT FROM A PAIR OF ANTENNAE IS STRONGEST ALONG A LINE CONNECTING THE ANTENNAE AND WEAKEST AT RIGHT ANGLES TO THEM

figure 8 with the axis of the two antennae along the vertical axis of the 8. If a given signal (such as the letter A which is •—) were sent continually from a pair of antennae, what would be heard by the pilot of a plane flying over the station?

If the plane were flying exactly in line with the antennae, the pilot would pick up the A signal—faint at first and gradually getting louder as the plane approached the station. The signal would reach its maximum strength just as the pilot reached the antennae; then for a few seconds when he was directly over them, the signal would black out completely and there would be silence. But almost immediately, if the pilot remained on this course, the signal would resume in full intensity and from that time would grow gradually weaker as the pilot sped away.

Now let the pilot change his course 90° and fly over the station at right angles to the antennae. At a distance the pilot hears nothing; as he approaches, still nothing; near the station the

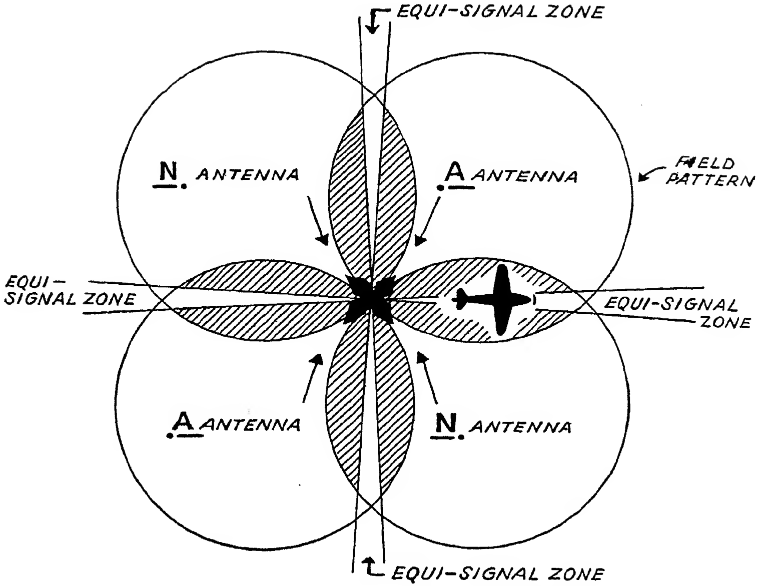
signal comes in faintly; over the station, nothing; then the faint signal again and still fainter as he flies away.

These are two extreme cases and if the pilot crossed over the station at any angle but 90° to the plane of the antennae he would hear the A signal. Its strength would depend on two things—on his nearness to the station and on the angle at which the station was being approached. If his course was 75° to the antennae direction, the signal would be quite weak. It would increase as he neared the station, but would never reach a maximum anywhere near that heard by the pilot in a plane flying in line with the antennae.

This will give you an idea how a radio signal can be used to guide a plane. But in actual practice the system used is twice as involved as the one just described. Actually, there are two pairs of antennae set at right angles or nearly so. One pair transmits a figure 8 pattern of A signals (· —). The other pair transmits a figure 8 pattern of N signals (— ·). These figure 8's are at right angles. Therefore when the N signal is strongest the A will be weakest and vice versa. A pilot flying at an angle that bisected the A and N zones would hear both signals at equal intensity as the zones overlap slightly. The · — and — · would blend together into the continual buzz which marks the equisignal zone. The equisignal zone is the *beam* that the pilot flies—it marks his course. As long as the continual buzz comes through the earphones, the pilot can relax on the beam. When the signals separate so that either the A or N is louder, the pilot is on one side of the beam.

Courtesy of Civil Aeronautics Administration

TWO PAIRS OF ANTENNAE SENDING OUT THE RADIO BEAM CAN BE CLEARLY SEEN AT THIS AIRWAY RADIO STATION



TWO PAIRS OF ANTENNAE SET AT RIGHT ANGLES, EACH TRANSMITTING A DIFFERENT SIGNAL, FORM THE BASIS FOR THE RADIO BEAM

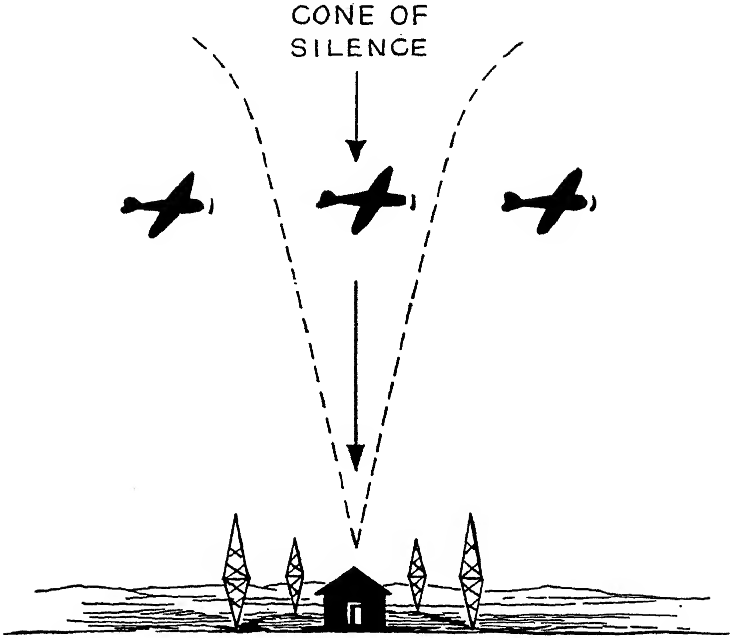
As you probably expect by now, the practice is a bit different from the theory. The radio range is most effective when the equi-signal zones—or beams—are set in line with the airway route. To do this the two figure 8's may not be at right angles and the A and N zones will therefore not be of equal area. But since the important thing is to have the beam set with the airway course these divergences do not matter. The pattern of signal sent out from a radio marker is shown in the illustration. The A and N zones alternate, but they are so arranged that the true north

line from the station passes through the N quadrant. Should the true north line coincide with an equisignal zone, then the zone to the west of north would be the N signal zone.

With this type of radio beacon, a pilot can locate himself if he is anywhere within the range of the signal. If the flier is on the beam, he merely continues to listen to the buzz. After 25 seconds the monotone will be interrupted by the call letters of the beacon—two letters sent in Morse code—and again the monotone will continue. The pilot learns to tune his radio so that this signal is weak—then if he is approaching the station the increase in volume will be clearly evident. As he passes directly over the station he enters the *cone of silence* and the signal stops, but he picks it up again almost immediately and can follow the beam away from the station. But from now on the signal strength becomes weaker.

The beam, or zone of equisignal strength, is about 3° wide and, of course, fans out as the distance from the station increases. Following a beam toward a station is like rolling through a long narrow funnel. In actual width the beam gets narrower and narrower, bringing the plane in a more exact line to the station. As the plane leaves the station, the reverse is true. The beam gradually broadens and is no longer as accurate a guide to the pilot. Under these conditions, to hold more accurately to his course the pilot uses his other instruments as well—his compass and his directional gyro.

A pilot need not be on the beam to make use of the radio range. He can enter the radio range at any angle and locate



THE BEAM SIGNAL FADES COMPLETELY IN THE CONE OF SILENCE DIRECTLY OVER THE STATION. THIS FADING GIVES THE PILOT A "FIX"

himself in short order. As soon as he hears the A or N signal he can locate himself in one of the two quadrants in which that letter is heard. He will soon hear the call letters of the station and if he does not recognize them immediately, reference to a list or to his navigation chart will give him the location of the station sending out the signal. Next he can turn the radio down low and can tell from the change in signal strength if he is approaching the station or leaving it. The pilot can listen for

the signal from the other quadrant. If he is exactly on the axis of the N zone he will hear the N and nothing more, but on either side he will hear the A signal, too. The strength of the A signal will depend on the angle the plane is flying. If it gradually increases in strength till it balances the N signal and blends with it, then the avigator has hit the beam and can follow it toward or away from the station.

Even this is not necessary unless the pilot wishes to locate himself accurately at the station. As soon as the pilot passes the station at any angle, off the beam, he will know this because of a reversal of signals. He will hear the — · in the N zone, but as soon as he passes the station, he will enter an A zone and will hear the · — instead.

These methods are mentioned here in a general way so you will understand how useful a beam marker is to the pilot. The pilot himself knows several specific methods for getting on the beam as soon as he has come within range of the station. These methods involve 90° turns, and the fading of signals. The procedures have been standardized. Under normal conditions the pilot can easily get on the beam.

Some pilots prefer not to fly exactly on the beam but a bit to one side where they can hear the A and N signals distinctly instead of the equisignal buzz. This has its advantages in bad weather when there are radio disturbances. Under these conditions it is easier to follow a distinct A and N signal as the monotone may be lost in the static. Air regulations require that, on a beam, the pilot keep to the right, as a safety measure. A

beam may be flown both ways and it is important to guard against head-on collision.

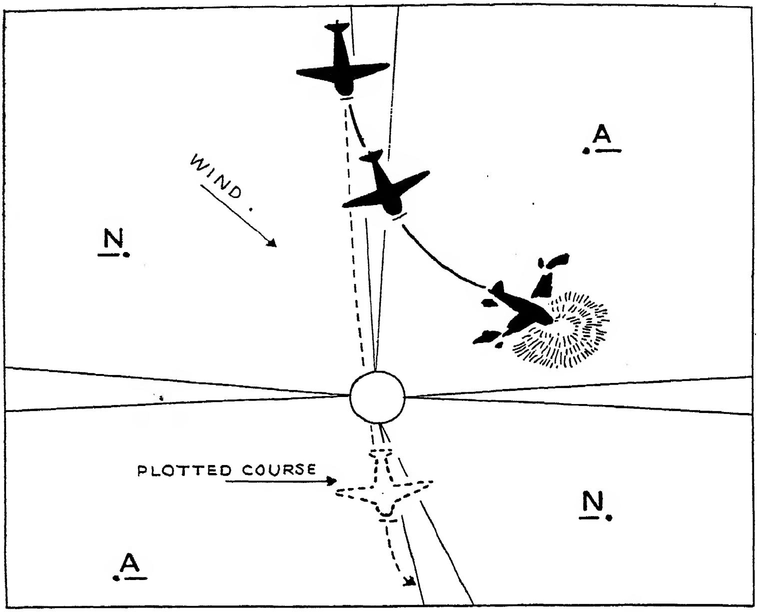
The radio beam sounds like the solution to all the avigator's problems. If he stays on the beam and maintains his altitude, there isn't much to worry about. Then why bother with a compass, directional gyro, automatic pilot, and all that? The answer lies in the fact that no single instrument is perfect. There are times when each may be doubted—the compass, the altimeter, and the radio beam.

For example, in mountainous areas, as around Salt Lake City, the equisignal area seems to break up into a series of narrow A and N beams instead of the blended on-course signal. This condition is known as a multiple course and may confuse the pilot. However, the multiple course may be recognized because the component bands are very narrow, but their total width may be 10° or more. Then, fading of the radio signal produces false cones of silence and the pilot may believe he is directly over a station when he is not. Also in the mountains the radio beams bend from their straight line paths. The bends may be fairly large, but as the bend is away from an obstruction, such as a mountain, it does not ordinarily lead the pilot into danger.

The pilot who relies too much on his beam and neglects the other factors of avigation may head for trouble. Here is what might happen. (And similar things have happened.) Let us ride with this over-confident pilot who is flying at 10,000 feet just north of the beam that brings him over the station at 78°. His flight calls for a change of direction after he has reached

the station. From then on he turns and follows a course of 190°. He hears his N signal and knows that as soon as he passes the station it will change to A. Then he can safely make his left turn, avoiding the high mountains that lie to the southeast of the station. But our over-confident aviator has neglected his drift. He is flying into a stiff 320° wind that is pushing him more and more toward the southeast. However, he hears the steady N in his earphones and is sure everything is right. Then the N changes to A. Our pilot smiles and swings his course from 78° to 190°. Now that he is set on his 190° course we had better unbuckle our safety belts and bail out while there is still time. Our pilot has not passed the station at all. The 320° wind has caused the plane to drift over into the next quadrant south. The A signal is that of the southeast quadrant and not the northwest, and the plane is headed straight for the mountains.

We can at least profit from this experience to the extent of remembering how important it is to check and recheck in avigation. Every last possibility of error must be eliminated. That is why the CAA (Civil Aeronautics Administration) has continually improved the radio range. Every effort is being made to make the range foolproof and to increase its use to the avigator. One recent improvement is to do away with the cone of silence. Instead, a special high frequency signal is sent vertically over the station. A small special receiver is needed to pick it up, but this requires little attention from the pilot. As soon as he enters the cone of silence, the *Z signal* is picked up—a light goes on at the receiver and the pilot has his radio *fix*—or in less



THE PILOT WHO NEGLECTS DRIFT MAY FIND THE RADIO BEAM MISLEADING. IN THIS CASE THE CHANGE FROM THE "N" TO "A" SIGNAL MEANS THAT THE PILOT HAS BEEN BLOWN OFF HIS COURSE INSTEAD OF FLYING PAST THE RADIO BEAM

technical language, he has located himself accurately over the station by use of radio.

The wave length of radio beacons is also being shortened. These shorter, high frequency waves are less subject to interference and to such effect as multiple courses. Present stations are being built so that simultaneous broadcasts of quadrant signals and voice are possible. Thus the pilot can communicate

with the station without losing track of his position.

Along the radio range are radio marker stations and the more recent fan markers. The radio marker beacons send out a distinctive signal of low power at the same wave length as the range signal. These markers are often located at the junction of two radio ranges and their signal not only helps the pilot make a fix but also reminds him to tune in on the new range. The pilot can establish contact with the operator at the marker beacon and obtain the latest weather reports or data on other planes flying the range.

The fan beacons are automatic high frequency installations, broadcasting at 75 megacycles. They are located on the radio range about 20 miles from the range station. There may be from one to four fan markers on the range, depending on how many of the range courses are on the airways. At Newark, N. J., for example, three of the range courses are used, the fourth goes out to sea and has no value to pilots, so that only three fan markers are installed. The fan station on the north course, or the course nearest to north in a clockwise direction, sends out a signal of one dash. Continuing clockwise, the next sends out two, three, or four dashes, depending on which course the fan station is located.

The fan marker tells a pilot flying a radio beam just which course he is on and, since this is a low-powered signal picked up only near the marker, it accurately locates the plane on the course. The markers are all about the same distance from the station at the airport, so the fan signal also indicates that

the pilot should report his position for traffic control.

Still further protection for pilots flying the range comes from the rules that require pilots to fly to the right side of the course and require planes going in different directions on the course to fly at different altitudes. In one direction the planes fly at even thousand foot levels, 6,000, 8,000, 10,000 feet, etc., and in the opposite direction the planes fly at odd thousands of feet.

Fliers all over the United States are constantly using the radio aids available to them. The radio ranges cover more than 30,000 miles of airways, and the air program has really just started. As of 1941, the radio aids included the following: simultaneous (voice and code) radio stations, 171; loop type radio ranges, 105; ultra-high frequency ranges, 8; radio fan markers, 122; and other radio markers and stations, 48. Besides, there are about 900 broadcasting stations that can be used as "beacons" by all planes equipped with the radio compass or the radio direction finder.

14

THE RADIO COMPASS

An earlier type of radio range station made use of a loop antenna. The loop transmitted a figure 8 pattern, directional signal, just as is done by a pair of vertical antennae. The loop antenna has certain disadvantages in night transmission that are leading to its elimination from radio range work. The directional principle of the loop still holds good but its present use is at the receiving end of the radio chain. Now the loop antenna is the core of a group of important radio instruments—radio compasses and radio direction finders.

The same mechanism operates in both the radio compass and the radio direction finder. When the receiving loop is turned in the direction of the sending station, the signal is received with maximum intensity. At right angles to the station, the signal is weakest or is not heard at all. The radio compass has a fixed loop antenna at right angles to the longitudinal axis of the plane. These loops vary in size from about 6 to 20 inches in diameter and are usually built inside of a shielded tube so the loop will operate in spite of severe precipitation static.

In the radio compass the loop cannot be rotated. The loop is connected to a radio, using two or three tuning bands, and to a sensitive electrical instrument that responds to the strength of

the incoming signal. The radio compass is a "homing device" —that is, it can be used to direct the plane to any station, aeronautical or commercial, that can be picked up by the plane's receiver. In operation, the pilot first tunes his set and picks up the station toward which he wants to travel. A chart is important to locate the station after it has been identified. Since any station can be used in homing with the radio compass, the compass can be used both on and off the airways.

The pilot now turns his plane till the signal becomes fainter and fainter. At the same time the needle on the indicator moves closer to the center point on the dial. When the needle is on dead center, the signal is *null,* as the loop is located at right angles to the plane's axis. The pilot has his bearing and can set the plane on a course toward the station. He follows this course as long as the needle stays at the center point. Should the plane turn off the course, the angle between the loop and the station will change, the station will come in stronger and the needle will move either right or left, indicating the departure from the heading.

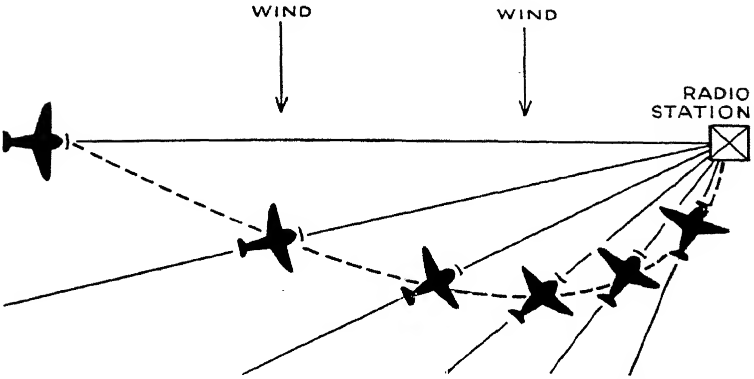
The null will be indicated when the plane is flying directly toward or directly away from the station. This may be a source of confusion to the pilot—a confusion that can be eliminated by the installation of a second antenna known as a *sense antenna.* The sense antenna may be another loop at right angles to the first, or it may be a vertical rod or horizontal wire. The sense antenna modifies the loop pattern, and as a result the null is obtained only in one direction—not two.

Official Photograph, U. S. Army Air Forces

THE RADIO COMPASS PERMITS THE PILOT TO USE ANY BROADCASTING STATION AS AN AID IN HIS NAVIGATION

Official Photograph, U. S. Army Air Forces

THE DRIFT METER ENABLES THE NAVIGATOR TO MAKE MORE EFFICIENT USE OF HIS RADIO AIDS



IN USING THE RADIO COMPASS THE PILOT MUST ALLOW FOR WIND. WHILE THE COMPASS WILL POINT TOWARD HOME, THE PLANE'S TRACK MAY BE MUCH LONGER BECAUSE OF DRIFT

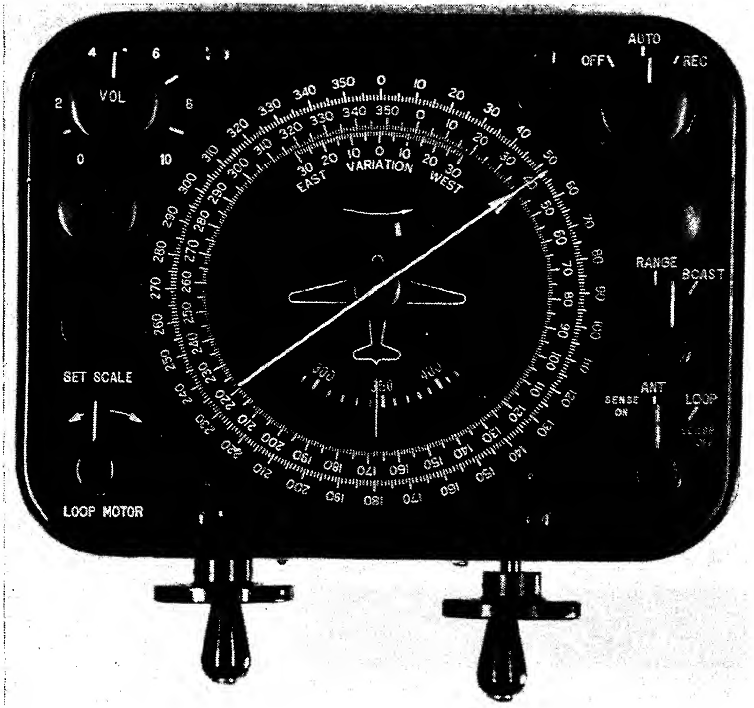
Drift is also a problem in using the radio compass as it is with the radio range. As long as the nose of the plane is pointed toward the station, the indicator shows "on course." Actually, if the wind is of sufficient strength and in the right direction, the plane may be taking a much longer path and swinging along a longer curved track. The pilot should know the wind direction and velocity and should edge into the wind frequently to keep close to his direct course.

The radio direction finder is a more elaborate piece of apparatus. The receiver produces signals that the pilot may either see or hear, but the important difference from the radio compass is that the loop antenna may be rotated. With this, it is possible to obtain a null without changing the direction of the plane

and hence get a bearing on the radio station without altering the course of the plane first. The radio direction finder exists in a number of forms. Different manufacturers of apparatus have included special features in their own models that may present an added advantage.

The radio direction finder has a loop that may be rotated mechanically or by an electric motor. This connects to the radio. A calibrated plate or dial shows the direction of the loop. The radio direction finder does not have the same indicator dial as the radio compass. The pilot determines his null point as the signal disappears. He then gets his radio bearing from the loop plate which is marked in degrees. This bearing is more valuable than the homing device of the radio compass. The bearing (within limits of accuracy) may be used like any visual bearing in determining the plane's position and direction.

The radio direction finder may be operated with sufficient speed to get bearings on two or three stations within a short time. These may be plotted on the regional or sectional chart and their intersection gives the plane's position. Position may also be determined by two bearings on the same station, taken at intervals, or from bearings on different stations with a time interval between. In these latter cases more difficult mathematics is involved, using trigonometric tables. At any rate the avigator can make a fix and determine his position with reasonable accuracy. With the radio direction finder it is easy to correct for wind and keep the plane on its proper heading. If the pilot wants to know his drift accurately, he can also measure



Courtesy of Sperry Gyroscope Co., Inc.

USING THE RADIO DIRECTION FINDER THE PILOT CAN ESTABLISH HIS POSITION BY TUNING IN ON TWO OR MORE STATIONS

this by the radio direction finder.

There are operational errors in the radio direction finder that the avigator must know. Like the compass, the direction finder has a deviation error due to metallic and electric parts of the plane. The deviation correction is often made within

the instrument. Mountains may disturb the path of radio waves as they do those of the radio range. The null point may shift and be indistinct. A similar condition occurs at sunrise and sunset. Lastly, there is the matter of static. Rain striking the metal parts of the plane releases electrical charges that accumulate and interfere with the loop. When static is severe the "sense antenna" must be disconnected, as this wire, unlike the loop, is not shielded.

The modifications of the radio direction finder include instruments that automatically make the corrections for variation and deviation so that a compass course is indicated and can be followed directly. There is also the *automatic radio direction finder* that keeps a needle pointing towards a station, once the pilot has tuned in. The plane may turn or drift but the automatic radio direction finder will keep the loop aligned in the correct position. The indicator connected with it will show the station's direction. This automatic direction finder keeps constantly on the null, freeing the pilot to do other tasks. Still another modification combines the automatic radio direction finder and the directional gyro. With this the pilot can set his dial to any desired track and then tune in on any radio station. The instrument will indicate the desired track which the pilot can easily follow.

Under favorable conditions the entire avigation of a plane can be done with radio instruments. The fact that transport planes are equipped with both the usual avigation instruments and the radio system as well is a complete double-check in fly-

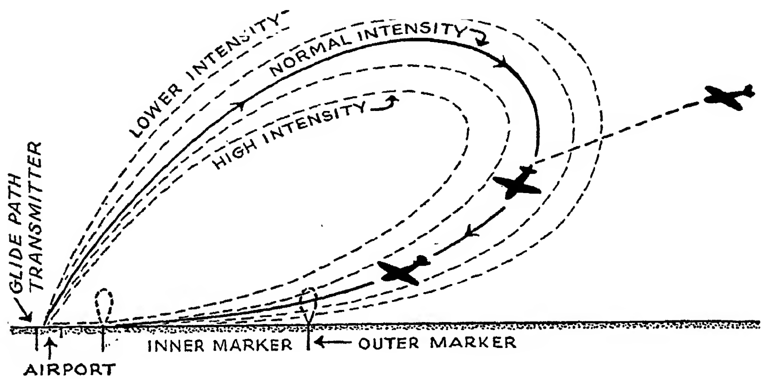
ing. The radio direction finder permits the use of nearly 900 commercial radio stations as well as about 300 airway stations as avigation aids. With such help, new records of safety and dependability in keeping scheduled flights have been reached. In 1941 over 95% of airline flights were completed on schedule.

Radio goes even further in its assistance to flying. Instrument flying requires a ceiling of at least 300 feet before the meteorologist can permit a flight. With the new instrument landing equipment and technique, planes may land and take off when both ceiling and visibility are reduced to zero. Experimental work on instrument landing has been going on for fifteen years. The CAA has installed at Indianapolis, Ind., an experimental station that includes the best features of several different instrument landing systems. Undoubtedly this type of avigation aid will continue to be developed until visibility and ceiling are no longer severe limitations to flight. Instrument flying with these aids is often called "blind" flying. That term is misleading as the pilot, instead of flying blind and helpless, may have his plane under as safe control as if visibility and ceiling were unlimited.

The instrument landing system provides control in three ways. First, there is a "runway localizer"—a radio beam that enables the plane to orient itself over the runway. Second, there is a glide path—a beam that indicates a path of descent for the plane at the proper angle to bring it into the runway. Third, a pair of marker beacons is set across the runway localizer and

glide path so the pilot is informed of his progress as he approaches the field on an instrument landing.

In landing by the use of instruments, the pilot follows a definite procedure. He follows the radio range to the airport and then makes what is known as a procedure turn. This enables



THE GLIDE PATH TRANSMITTER OF THE INSTRUMENT LANDING SYSTEM PROVIDES A RADIO BEAM THAT LEADS THE PLANE DIRECTLY TO THE AIRPORT RUNWAY

him to strike the runway localizer and glide path at an elevation of about 1,500 feet above the field at a distance of about 5 miles from the runway.

The localizer is a vertical radio beam centered over the runway of the airport. The instrument indicator in the plane will show dead center when on this beam. The localizer line will swing to left or right, if the plane is on either side of the localizer beam. These directions are marked in color corresponding

to the same colors used to indicate positions on a plane in flight. These are a red light on the left wing and a green light on the right. In the same way the left of the runway localizer is the red section and the right, the green.

The runway localizer uses a high frequency signal (109.9 megacycles) and transmits two tones that, according to their intensity, move the instrument indicator line to the red or green areas, or hit the center when the ship is on course.

The glide path transmitter operates at a slightly lower frequency (93.9 megacycles) and sends a signal that might best be pictured as a pear-shaped plane with the point at the runway. In this pear-shaped plane, the signals near the core are of the highest intensity and those at the outside are of lowest. In between is a line of medium or normal intensity that represents the glide path.

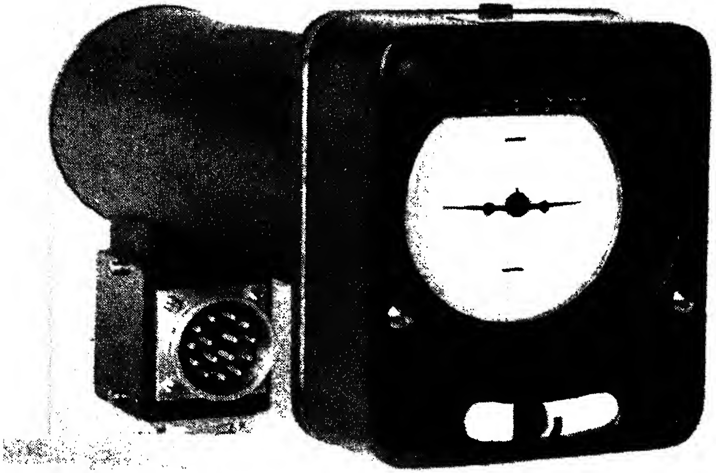
On completing his procedure turn, the pilot intersects the runway localizer and glide path at an elevation of 1,500 feet 5 miles from the runway. If he remains on course and glides at an angle of about 4°, he will hit ground on the runway. If the pilot is flying too high on the glide path, he enters an area of higher signal intensity—if he flies too low, the signal intensity is also lower. These differences in intensity are indicated by a horizontal line on the instrument landing dial. Flying too high or too low causes the plane image to appear above or below the glide line on the dial.

The runway localizer and the glide path give the pilot his basic guidance. There is only one more factor he must know—

his distance from the airport. This information he gets from two radio markers that send out a vertical fan-shaped signal across the glide path and runway localizer. These markers are of the same type as those used for the cone of silence marker and the fan markers on the radio range. They operate at 75 megacycles and illuminate a signal light in the plane. When the plane passes over the outer marker—about 2½ miles from the runway—a purple light flashes twice a second on the pilot's indicator board. At this point he knows that his elevation above the field is 510 feet.

Continuing on his glide, the pilot hits the inner marker beacon one half mile from the end of the runway at an elevation of 45 feet. Now an amber light flashes 6 times a second and tells the pilot that the time to set the plane down has come. By now the pilot has slowed down to a safe landing speed. He has made sure—even before he hit the outer beacon—that he was exactly on the course and at the correct glide. He has made any necessary allowance for wind and has had all his instructions from the traffic control tower of the airport. Less than a minute after he has passed the inner beacon, the plane is on the ground and the pilot is taxiing up to the hangar.

When the pilot is as close as the inner beacon he is no longer flying "blind" even in a heavy fog. The airport lights will come through quite well at that distance. The approach to the runway is marked by lights 200 feet apart. Nearer, the lights are 100 feet apart and along the runway a flush type lighting is used. At Indianapolis where this system was developed by the CAA



Courtesy of Sperry Gyroscope Co., Inc.

THE FLIGHTRAY IS THE LATEST IN NAVIGATION INSTRUMENTS. IT HAS BEEN HIGHLY SUCCESSFUL IN EXPERIMENTAL TRIALS

there is an additional lighting aid. Tubular neon lights have been set along the approach so the pilot can see them even before he hits the inner radio marker. The red rays from the neon lamps are very efficient in penetrating fog.

There are two other radio instruments that should be mentioned. The Flightray seems the ultimate instrument for avigation. It is a combination of radio instrument landing device, gyro-horizon, directional gyro, altimeter, air speed indicator, and radio compass. This Flightray produces a series of luminous marks on a screen before the pilot. These are formed by

cathode rays. The series of marks show the plane silhouette in relation to lines for speed, direction, landing path, etc. The purple and amber marker lights, as well as a bank indicator, are incorporated. This instrument has brought the important aids to instrument flying into a compact system that will make observation and maintenance of course still easier when the instrument is perfected.

The terrain clearance indicator is not yet practical. Its importance is already established, but the bulk and cost of the instrument still weigh against its use in any but the largest planes. The action of the terrain clearance indicator depends on the reflection of ultra-high frequency radio waves from the earth. These are sent out from a transmitter at an average frequency of 450 megacycles. Two small antennae are used and are connected to the instrument by special co-axial cables. The radio waves are reflected back and arrive "out of step" with the transmitted waves in an amount proportional to the height of the plane. This difference can be directly translated into feet and read off a dial. The terrain clearance indicator is accurate to about 10% and gives readings at distances from 20 to 5,000 feet above the ground. Such an absolute altimeter is a real asset in flying, as usual altimeter readings refer only to sea level. Not only does it assure the pilot of safety, but the experienced pilot can learn to associate typical changes in altitude with known landmarks such as a cliff, river valley, or mountain peak. In this way the terrain clearer may be used to check position.

All the radio instruments and especially those used in instru-

ment landing must be operated with a great deal of skill. It may sound simple in a book, but no amateur can undertake instrument flight and landing merely because he has an idea of how the instruments work. The peculiarities of the instruments must be known and their action under all conditions must be completely understood. The outer beacon signal indicates the plane's height of 510 feet above ground if everything is right. But it does not always indicate that height. As a matter of fact, a true indication of between 450 and 650 feet is close enough for a safe instrument landing.

Some instruments read high, others low. Some transmitters or some airport locations produce particular results that the pilot learns to know and keep in mind. Skill in instrument flying is a result of careful training and long experience. Even before the pilot begins real instrument flying, he spends hour after hour in the *Link Trainer* where conditions duplicate those of actual flight. Here the pilot flies his trainer safely on the ground till he has developed the skill he needs. The pilot who uses these latest instruments is successful not only because the avigation aids are good but because he is good also. Perhaps sometime in the future these aids will be so improved and so foolproof that almost anyone will be able to operate them—as some of us today operate automobiles—but till that time avigation will involve good training as well as good planes and instruments.

15

YOUR PLACE UNDER THE STARS

THIS is a good spot to make a "running fix" and check your bearings as you go through the book. By now you are well aware that avigation involves several important component subjects, brought together and applied to the specific problem of getting a plane to its destination in the shortest and safest manner. Each phase of avigation acts as a check on the others and successful piloting cannot be achieved unless the man at the controls is familiar with the entire range of the subject.

First you had a look at the job of using maps and charts. You appreciate the difficulties in mapping a spherical globe and you probably understand the matters of projection, scales, and symbols. With your knowledge of charts you have been able to consider the compass, direction, and position. You know the elements in plotting a course.

You have also made acquaintance with the basic facts of meteorology. Air pressure, precipitation, winds, fog, and cold fronts are now perhaps clearer in your mind. You have had a glimpse at the avigation instruments and at instrument flying. You are on speaking terms with pressure, gyroscopic, and radio instruments. Now is the time to ask, "Where do we go from

here?"

There is still one phase of avigation that has not been mentioned. Perhaps the book should have started with it—since it is the oldest and most respected branch of the subject. In the old days, celestial navigation *was* navigation. It was the sound, mathematical-astronomical science that brought whalers and clipper ships safely to port. It was the basis of training for the officers who trod the decks of wood and steel ships.

This doesn't mean that celestial navigation is an art of the past—quite the contrary. It does mean that since the days when celestial navigation was all-important there have been new discoveries and inventions. We have new techniques and new problems that frequently meet the situation better than the older methods. With a knowledge of instrument flying and the use of radio aids, one can avigate successfully without knowing one star from another. In the future, as radio aids are developed, there may be even less use for the older methods, but to discard them as dated would be throwing away a tried and true tool that still has many uses.

Celestial navigation includes the determining of position by observation of stars, planets, the sun and moon. On short flights this may never be used. Certainly the use of celestial navigation on flights of less than 1,000 miles is unnecessary, especially since observations can only be made when visibility is good. You must not forget the other side of the story—the fact that flights are getting longer and longer. Better engines, better planes, and the entire march of air power have pointed to more

and more long non-stop flights. The Atlantic is no longer an obstacle. Other ocean barriers are yielding fast. New air routes are being established in tropical and arctic regions far off the usual beaten tracks.

For these long flights, in regions where marked airways and radio guides are lacking, the avigator must depend on celestial navigation to check his instrument flying and dead reckoning. Under these conditions the subject is just as important as it ever was—and perhaps more so because one cannot afford to get lost over tropic jungles or over the arctic wastes. There is also a safety factor in knowing celestial navigation, even if its use may seem limited. One additional source of data can do no harm. An additional method of checking position at night is really worth knowing.

The Army or Navy pilot specializing in navigation is thoroughly grounded in celestial methods. It's an old story to Clipper pilots who fly scheduled routes across the Atlantic and Pacific. Not so very long ago TWA, realizing the importance of long range flying, began to train its pilots in celestial navigation too. This study is now part of their training program. If you seriously expect to travel far and wide on wings, celestial navigation is essential.

There is one last point—not of much practical importance, but worth considering. A pilot spends a good deal of time up in the air. He gets a chance to see a lot of the sky—perhaps more than most other people. He has the opportunity to see the sun, moon, and stars in their full glory. It wouldn't be normal

if he hadn't a natural curiosity about these heavenly bodies. So pilots usually know a great deal about celestial objects, for one or more of these reasons.

A pilot uses the sky as he does a chart. He determines his position from the heavenly bodies as he does from landmarks or from radio stations. The only difference is that the pilot does not usually take out a chart to identify each star or planet. He is familiar with enough of them so he can proceed at once with the business of determining position. He cannot take the time to learn to know the stars the moment he wants to use them. He learns how first.

Learning to know the stars is the first step in celestial navigation. Let's take it for granted that the sun and moon are already familiar. The stars are also suns, generally like our own, but often larger and hotter. Many give out more light than our sun, but because they are incredibly farther away, the light we receive is infinitely less. The story of the stars and their place in the vast universe is in itself fascinating, but we cannot consider it here. We must limit our attention to the identification of stars and star groups that will aid the avigator in his work.

It may be a paradox, but in order to use stars for the purpose of avigation, it is more practical to use a less scientific method of locating and identifying them. Astronomers who deal with thousands upon thousands of stars, most of which are invisible to the unaided eye, locate these distinct bodies by two circles on the celestial sphere—*declination* and *right ascension*, cor-

responding to the latitude and longitude used on our terrestrial sphere. If we were to consider many stars, or the less conspicuous ones, that method would undoubtedly be the best. But for celestial navigation a knowledge of about twenty or so principal stars and their location is adequate. These can be located more easily by their position in constellations than by the more scientific lines of reference, just as Chicago, San Francisco, and New York are more readily identified as being in Illinois, California, and New York than if the more accurate but less familiar latitude and longitude positions were used.

There seems to have been a good deal of specialization in the early days of astronomy. The Arabs (as famous in astronomy as they are for their number system) gave names to the principal stars—names these stars still bear today. The equally famous Greeks gave their attention to the apparent star groups—the constellations—and these groups generally bear the names of figures in Greek mythology.

Perhaps by chance, the Arabs were on the better track. A star is a star and everyone recognizes a particular star by its color, brightness, and position in relation to other stars. But a star group or constellation is another matter. What looks like a dragon to the Greeks may look like an elephant, a rectangle, a bunch of bananas, or nothing at all to you. The star groups are imaginative arrangements of stars representing some shape or design. Sometimes the design is obvious, sometimes it is difficult to trace. If stars in any particular constellation are related, it is likely to be a matter of coincidence. Stars in such familiar

groups as Orion and the Big Dipper are not only billions of miles apart, but often move in different directions and are otherwise unrelated.

Yet for rapid identification, these constellations are a help that no pilot can ignore. But remember that outside of a possible value in literature and mythology constellations have little use in astronomy except as a rough guide to the brighter stars.

It will aid you in locating stars and star groups to recall what you already know about earth movements. Because the earth revolves, not only the sun but the stars appear to move from east to west. A group of stars in the east at 9 P.M. will be overhead or to the south by midnight and later will move into the western sky. Because of this daily motion, stars will be farther west as the night progresses.

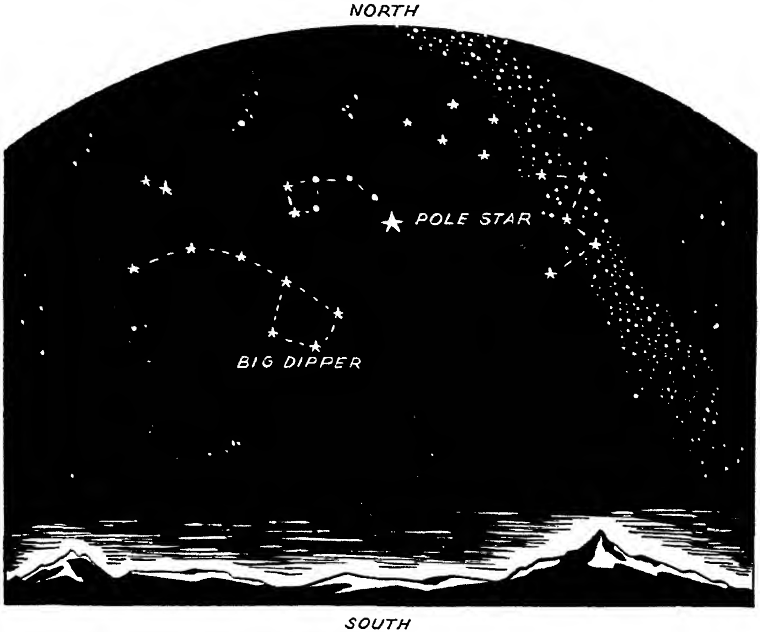
The earth revolves around the sun—taking a year for a trip on its orbit. This produces another apparent motion of the stars. A line drawn from the sun past the earth in July could be extended out into space to a certain star group. A month later the line from the sun would miss the first star group and might be close to another. Six months later the extended line would point in the opposite direction from that of July.

Thus the stars we see overhead at 9 P.M. in July will be different from those overhead at the same time in September and March. To get a picture of the most important stars visible during the year it is necessary to look at the sky each month and follow the star groups as their position gradually changes. Next best is to know at least the main summer and winter constel-

lations and their principal stars. With all this you must remember that the spherical earth limits the horizon and that the stars you will see here in the United States will be quite different from those another observer would view in Argentina.

You will probably want to know the Pole Star first, though as far as celestial navigation is concerned one star will often do as well as another, as long as you know what star it is. The Pole Star is a star of second magnitude—that is, it is $2/5$ as bright as a first magnitude star. A third magnitude star is $2/5$ as bright as one of second magnitude, etc. Stars down to 6th magnitude—about 5,000 of them—are visible on a clear night, but of them all only 20 are first magnitude stars. The brightness of stars is an individual matter and there is a good deal of difference even between those classed as first magnitude.

To get back to the Pole Star. It is in the constellation of the Little Dipper—the end star of the handle. The Little Dipper is not as conspicuous as its bigger neighbor. In fact the Little Dipper is not very dipperlike since its handle bends toward the bowl. With the help of the chart on page 221 you can trace out the constellation. In locating the Pole Star, the Big Dipper is more help than the Little Dipper. The Big Dipper moves in a circle across the northern portion of the sky and in the United States can be seen at some time during every night. The Big Dipper needs no description. Seven second and third magnitude stars make up this group—four in the bucket and three in the handle. The two stars at the outer edge of the bucket point close to the North Star. The distance of the North Star from the



THE CIRCUMPOLAR CONSTELLATIONS ARE THE KEY GROUPS IN IDENTIFYING THE STARS

pointers is about five times the distance between the two pointers. Once you know the Big Dipper and the fainter Little Dipper you have an entering wedge into the constellations. Actually, both these star groups are fragments of larger constellations—the Big Dipper is part of Ursa Major—the big bear—and the Little Dipper is in Ursa Minor—the little bear.

Near the North Star, at an angle of about 140° with the bucket of the Dipper, is a W-shaped constellation. Actually it

has the W shape when in the east and as it moves west the W slowly turns over into an M. This is Cassiopeia. To the Greeks it represented Queen Cassiopeia seated in a chair, but only the five stars forming the chair are conspicuous. Between the two Dippers begins the constellation Draco—the dragon—that loops over the bucket of the Little Dipper. Directly across from the Big Dipper—in line with the pointers—is a faint rectangular group. This is the constellation Cepheus—the king. He was Queen Cassiopeia's husband, but she got the brighter stars. These five constellations are called the circumpolar constellations. They are so far north that their apparent movement about the North Star is more obvious than that of stars farther south that seem only to move across the sky. You should know the Dippers and Cassiopeia at least. When the Big Dipper is low in the sky and perhaps hidden by haze, Cassiopeia will be well above the horizon and can be used to locate the Pole Star.

On a winter evening the handle of the Big Dipper will be pointing toward the northern horizon, but in July it points almost directly across the overhead sky. Follow the curve of the handle of the Big Dipper southward. About twice the length of the handle you hit Arcturus, a first magnitude star in the constellation Bootes. Bootes is a kite-shaped star group extending in the direction of the Big Dipper. Arcturus is the base of the kite where the tail should be attached. Continuing the curve of the Big Dipper's handle brings you to Spica—another first magnitude star in the sprawling constellation Virgo. By now you have reached the southern part of the sky and to the east

NORTH

SOUTH

THE IMPORTANT CONSTELLATIONS AND FIRST MAGNITUDE STARS OF THE SUMMER SKY

of blue-white Spica you will find another first magnitude star—but this one has a distinct reddish color. This is Antares, the brightest star in the constellation Scorpio, that hangs along the southern horizon like a huge fish hook or a slightly crooked J.

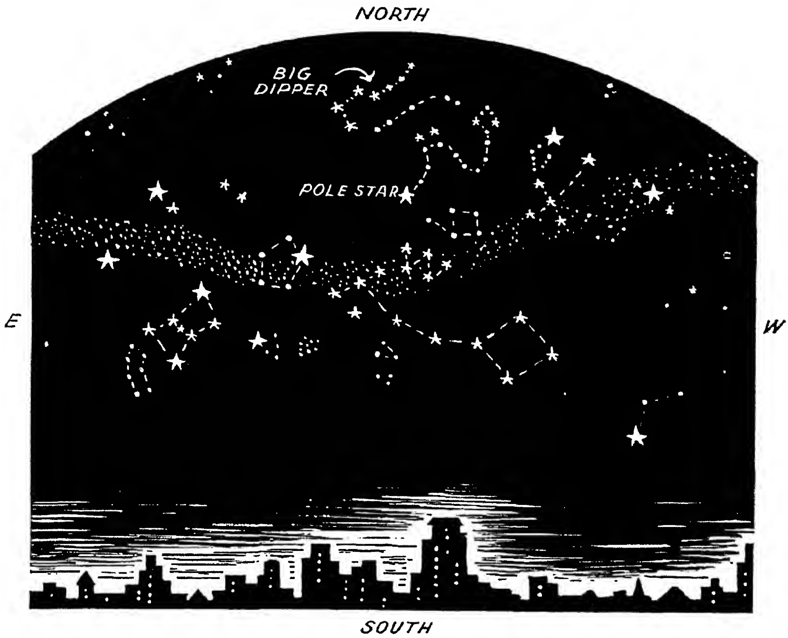
Near the top and just east of kite-shaped Bootes is a small ring of dim stars—forming the Northern Crown. Still further

east is another brilliant first magnitude star, Vega, in the small rectangular constellation the Lyre. Vega is almost on the edge of the Milky Way. And just north, in the Milky Way itself, is the Northern Cross. The Cross is rather long. It is oriented along the Milky Way and is composed of second and third magnitude stars, except for the top star in the Cross, Deneb—another first magnitude star. Below the Cross and still near Vega is a small, compact diamond of stars—the constellation of the Dolphin. Near by is the first magnitude star Altair with a third magnitude star close on either side. Altair is in the Eagle.

These are the major stars and star groups of the summer. By the time the earth has moved around its orbit for another six months an entirely new set of constellations is in the evening sky. Each night a given star is in the same position, about four minutes earlier, till it gradually disappears in the west with the setting sun.

The January sky is resplendent with first magnitude stars. You may as well start with the Big Dipper again, but this time use the two stars forming the *bottom* of the bucket as pointers. Extend a line south across the sky (again about five times the distance between the pointers) and you will strike a pair of brilliant stars. These are Castor and Pollux—in the constellation Gemini—the twins. Pollux is first magnitude and Castor is nearly so. The constellation extends westward in two parallel lines. Just south of the twins is another star of first magnitude, Procyon—the little dog star.

If you have progressed this far, you can't miss the most con-



THE IMPORTANT CONSTELLATIONS AND FIRST MAGNITUDE STARS OF THE WINTER SKY

spicuous of all constellations, Orion. Three second magnitude stars form the diagonal belt of the hunter. Betelgeuse, a huge sun of first magnitude, is at his right shoulder and Rigel, another first magnitude star, marks the left knee. The odd knee and shoulder are marked with second magnitude stars. The line of Orion's belt points to Sirius, the dog star, brightest star in the sky. Sirius is in the constellation Canis Major—the big dog. Four second magnitude and a number of third and fourth magnitude stars fill out the group.

Above Orion and to the west is Aldebaran, a reddish star in the constellation Taurus (the Bull), and near by is that beautiful and famous group, the Pleiades. Still farther north, about halfway between Pollux and Aldebaran, is Capella in the constellation Auriga. Another star group shaped like a sickle is conspicuous in the eastern sky. This is part of the constellation Leo. The end of the handle of the sickle is marked by Regulus, the last first magnitude star generally visible in the United States.

Don't expect to know the stars now that you have read quickly through these pages. Take the book out-of-doors on the next clear night. Pick a place where there is no artificial light to blind you. Get a good look at the star maps with your flashlight, then try to locate the stars and constellations. It will take you more than one evening to be sure of them. But once they are learned they are hard to forget. There are many books on the sky to help you further, if you desire to know more about the stars, their identification, and history.

You should also learn to know the planets. These shine in the sky because of light reflected from the sun. They are part of our solar system and are very much closer than the stars. Planets move across the sky along a path called the *ecliptic* and you must learn to know each individually. Venus is very bright. It only appears in the east or west, never overhead. Mars has a reddish color, and Jupiter, much brighter, is yellowish white.

Lastly, if you plan to use celestial navigation to its fullest, there are a number of southern constellations you should know as well as the first magnitude stars seen in the southern skies.

16

CELESTIAL NAVIGATION

CELESTIAL navigation involves the determining of position by use of observations made on the sun, moon, planets, or stars. The observer must have a sextant, a clock, chart, and certain mathematical tables. He must also have an approximate idea of his position.

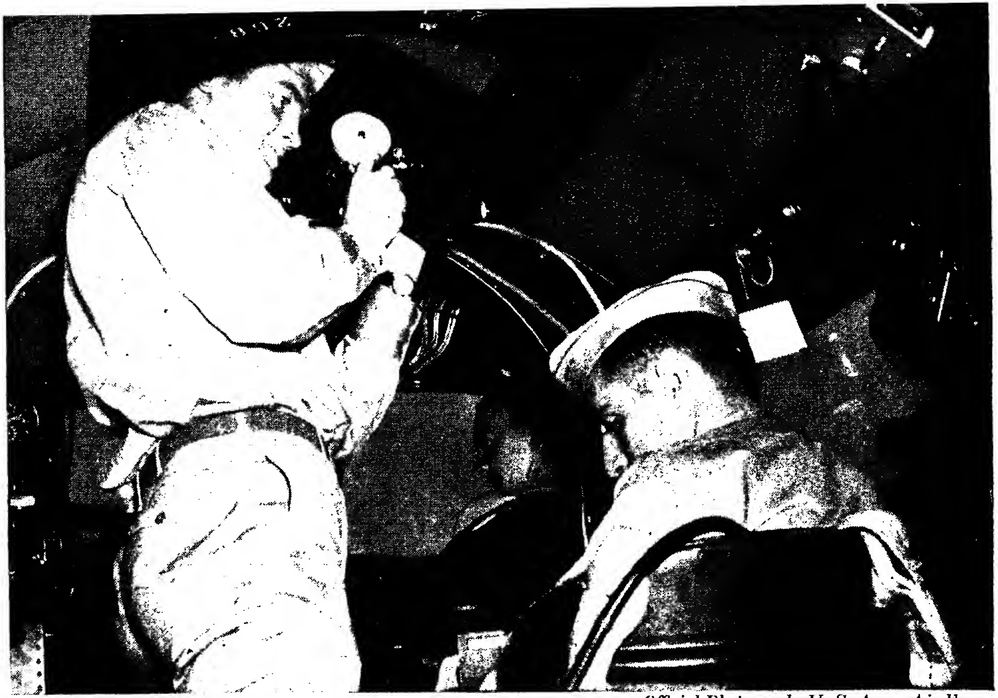
A great deal of mathematics is involved in these methods. Formerly a sound training in spherical trigonometry was the first step in navigation. Now the mathematics is reduced to nothing more than addition and subtraction. The work has all been done for you and the answers are found in the tables published in the Air Almanac.

Since January 1941, the United States Naval Observatory has been issuing the "American Air Almanac" as a companion volume to the "American Nautical Almanac" which has been, for years, a constant guide to sailors. The Air Almanac is specially designed to aid avigators. Its size is convenient for use in a plane. It is published in three sections, each covering four months of the year. The tables are so arranged that a single opening of the book will generally give the pilot all the data he needs to convert his observations into a fix. The simplified methods made possible by this book put celestial navigation on

a level where any pilot can master its principles.

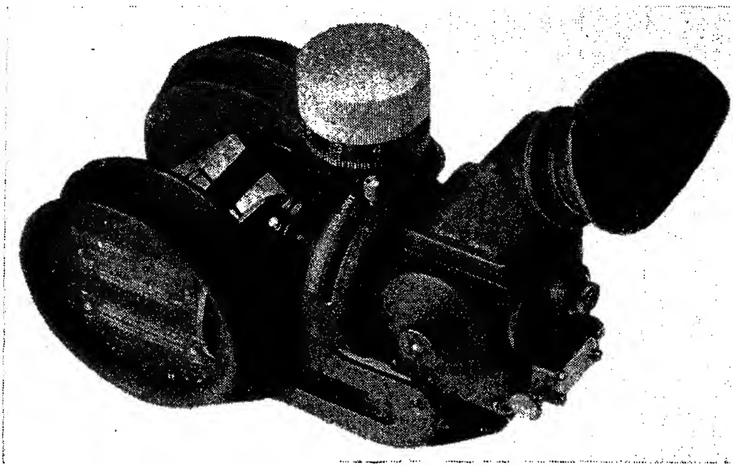
Even in a fast-moving plane, celestial navigation is reasonably accurate. Under average conditions, observations should yield a position that is within five or ten miles of being exactly true. For long distance flights that is close enough. If the air is rough and observations are inaccurate, the position computed from these observations will lack accuracy too. Like all other navigation, reference to a chart is essential. The Lambert projection, so suited to other aeronautical uses, is equally satisfactory for use with celestial navigation. A straight line on the chart approximates a great circle on earth, hence a bearing or *azimuth* (as it is called in celestial navigation) is easily plotted.

It is essential that the avigator know how to use a sextant. This is an old and honorable instrument of navigation, developed in 1730 from earlier instruments used by navigators since ancient times. The sextant does nothing more than measure the angular height of an object above the horizon. To do this accurately, the sextant is made to precision measurements and must be used in just the right way. After all, if position is determined from the observation, it can be no more accurate than the observations themselves. That is why the avigator, using the sextant, makes a series of observations—often ten in rapid succession—and uses the average of these for his computation. He measures the height of the star or sun to the nearest angular minute. He must also record—to the second—the time of making the observation.



Official Photograph, U. S. Army Air Forces

CELESTIAL NAVIGATION IS IMPORTANT FOR LONG FLIGHTS WHERE NO LANDMARKS ARE VISIBLE. THIS CADET IS "SHOOTING THE SUN"



Courtesy of Pioneer Instrument, Division of Bendix Aviation Corporation

THE OCTANT IS A SPECIAL FORM OF SEXTANT SUITABLE FOR USE IN PLANES

Practice is necessary in learning to use the sextant. There are corrections to be made for inaccuracies in the instrument itself. In most modern sextants an artificial or bubble horizon is used instead of the natural line where sea and sky seem to meet. With this type of sextant another correction is needed. There is also a correction for dip, since the pilot is above the horizon when he makes the observation. The angular correction to be added or subtracted from the average of the observed measurements is found in the Air Almanac tables. So there is no real difficulty in making these corrections.

The sextant itself has been modified for air use. Such a modification is the *octant,* a small, rugged, and highly accurate in-

Official Photograph, U. S. Army Air Forces

:ELESTIAL NAVIGATION IS ESPECIALLY IMPORTANT IN MILITARY FLY-
N ; WHERE THERE IS NO RADIO BEAM TO FOLLOW. ALL FLYING
CADETS MUST LEARN TO "SHOOT THE SUN"

strument for celestial navigation. Through the use of fixed and movable prisms, the star being observed is brought into line with the bubble of the artificial horizon. Carefully calibrated dials give a reading in degrees and minutes when the image is in the correct position. Luminous paint and special electrical illumination make this instrument easy to use in the dark. Its features permit a pilot to use it accurately from the cramped quarters of a cockpit.

A gyro-stabilized *panoramic sextant* has been developed with a rotating eyepiece. With this the avigator can take his observations from one seated position. Furthermore, a single observation will suffice in place of the ten needed when the sextant is held by hand.

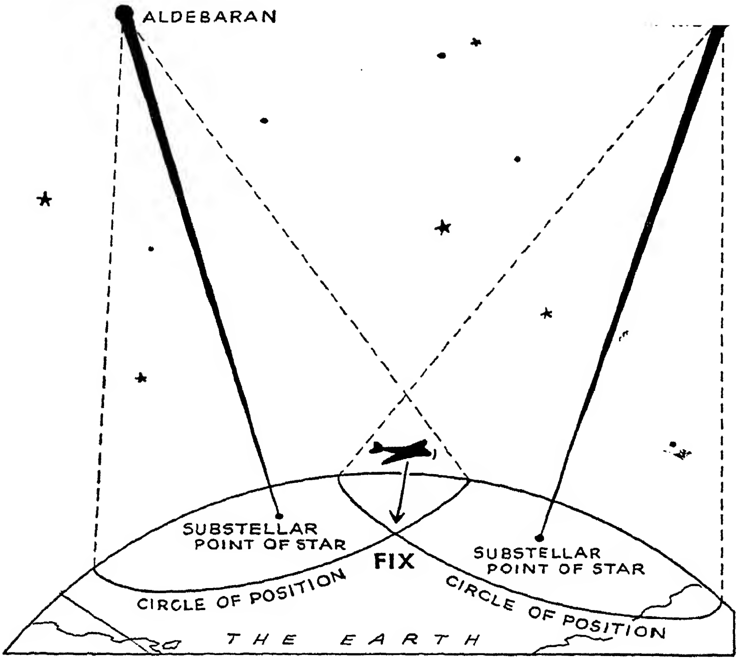
Since the sextant is used to measure the angular height of a star, planet, or the sun, this height must be significant in locating an object on the earth. Consider the North Star, in the light of your knowledge of the earth, and you will see the importance of this measure of altitude. There is only one place on the earth where the North Star is overhead—at the North Pole; only one place where it appears on the horizon—at the equator. At all other points between the equator and the North Pole, the elevation of the North Star will vary—depending on how far the observer is north of the equator or south of the Pole. If the observer is in the Caribbean Sea, 20° N. of the equator, the sextant will show the Pole Star 20° above the horizon. At any spot on the 40th parallel, in California, New Jersey, Spain, Turkey, or Japan, the North Star will appear 40° above the

horizon. In other words, the elevation of the Pole Star equals the latitude of the observer.

You could, if you wished, plot a series of concentric circles, 10° apart, around a point just under the North Star. (This would be the North Pole.) As you traveled from the center, the North Star would seem 10° lower as you went from circle to circle. If you made an observation with the sextant and found the angle of the North Star to be 70°, you would know you were somewhere on the 20° circle (90° − 70°), but you would not know exactly where. If you know where *any* star, planet, sun, or moon will be overhead at any specific time, you can do exactly the same thing.

Suppose you knew from tables that the first magnitude star Vega is overhead at a certain latitude at a certain time. You measure the star with your sextant at that second and find its altitude to be 47°. You immediately know that you are somewhere on a circle 43° (90° − 47°) from the point directly beneath Vega. You might take a Lambert or great circle chart, set one end of a divider at the point directly beneath Vega, and, using the same scale as the chart, lay out the circle 43° in radius. At the time of the observation you would have been somewhere on that circle. In navigational language you have established a *circle of position* on Vega.

This fact is not of much help by itself, but a second observation made on Polaris or another star would place you on a circle of position in relation to that star. If this second circle were plotted on the chart, using the same scale, the circles would



OBSERVATIONS OF THE ALTITUDES OF TWO STARS ENABLE THE NAVIGATOR TO COMPUTE HIS POSITION BY SIMPLE MATHEMATICS

be found to intersect and, of course, the observer's location would be at the point of intersection. A fix would be established from two circles of position.

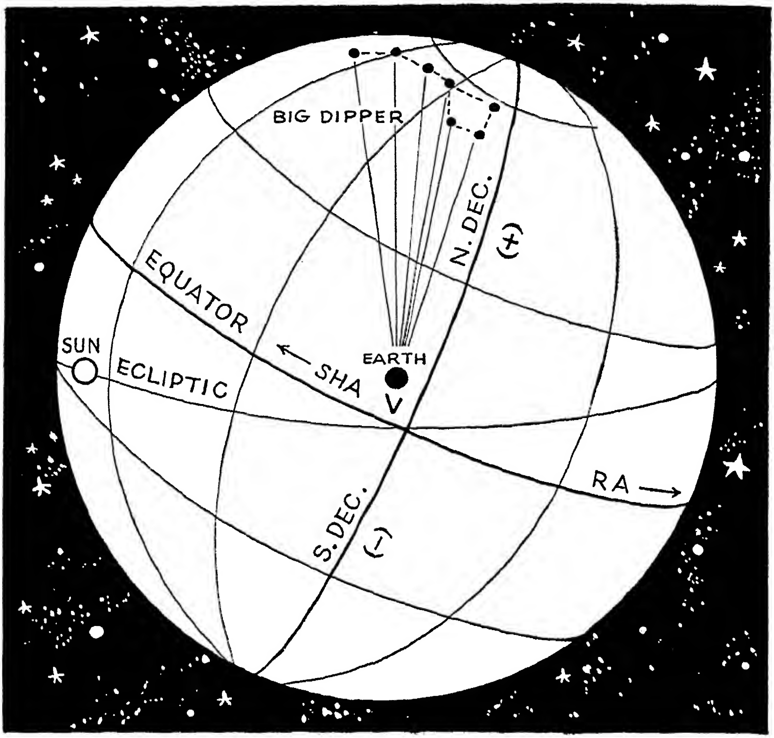
This sounds quite easy. It is—in theory. However, more refined methods are actually used to locate the plane with greater accuracy. The basic principles are the same except instead of using the entire circle of position, the avigator uses only a very

small part of such a circle—so small a part that it may reasonably be represented by a straight line—*a line of position.*

In many ways the use of the stars is similar to the use of lines of reference on our spherical earth. You might imagine that the sky is an inverted bowl with the stars dotting the inside and with the sun, moon, and planets moving on circular paths across the surface. Such an idea is far from the astronomical truth, but it enables us to see the relationship of the earth and the stars a bit more easily. With such a bowl of the sky covering the earth, you can, in your mind, project the lines of latitude and longitude up from the earth to the celestial sphere and use them in approximately the same way they are used here on earth. The differences are not of major importance.

The projected axis of the earth becomes the axis of the celestial sphere, about which the sun and stars *seem* to rotate from east to west, just as the earth really rotates from west to east on its axis. The projection of the equator becomes the celestial equator and measurements can be made north and south of it. But in the sky these measurements are called declination—plus declination is north of the celestial equator and minus declination is south.

The sky measurements of longitude are somewhat different from those on earth. Instead of using the Greenwich Meridian as an arbitrary starting point, astronomers make use of the place where the path of the sun crosses the celestial equator. You recall that because of the tilting of the earth's axis the sun apparently moves north of the equator in the summer and south



TERMS USED IN CELESTIAL NAVIGATION DESCRIBE THE POSITION OF HEAVENLY BODIES ON THE CELESTIAL SPHERE. DISTANCES NORTH OR SOUTH OF THE CELESTIAL EQUATOR ARE MEASURED IN DECLINATION (DEC.). LONGITUDINAL DISTANCES ARE MEASURED IN TERMS OF RIGHT ASCENSION (RA) OR SIDEREAL HOUR ANGLE (SHA) FROM THE POINT "V" (VERNAL EQUINOX)—THE POINT WHERE THE ECLIPTIC, APPARENT PATH OF THE SUN AND PLANETS, CROSSES THE CELESTIAL EQUATOR

in the winter. The sun crosses the celestial equator on exactly the first day of spring and the first day of fall. This crossing of the ecliptic (apparent path of the sun and planets) and the celestial equator at the spring or *vernal equinox* is the starting point from which celestial *right ascension* (or longitude) is measured. Right ascension is measured toward the *east* from the vernal equinox. Instead of being measured in degrees, it is measured in hours, minutes, and seconds.

Longitude degree measure and time measure are easily interchanged. It is 360° around the earth and a single revolution takes almost exactly 24 hours. Hence any places differing by 15° east or west also differ by one hour of time. New York City, close to 75° west of Greenwich, is five hours behind Greenwich in time. It is simple arithmetic to convert degree measure to time measure. Knowing the longitude of any two places, the time difference is quickly found or vice versa.

The same relationship may be used in celestial measurements. The right ascension measurements on a 24-hour time scale are the equivalent of degree measure of longitude. Another celestial measure of longitude is used. This is the *sidereal hour angle* (abbreviated SHA, in tables). This is measured to the *west* from the vernal equinox in degrees—from 0° to 360°. Since the right ascension (RA) can be converted into degrees, the SHA equals 360° minus RA. Data for some of the first magnitude stars listed in the Air Almanac appear as follows:

Name	*Magnitude*	*SHA* ° ′	*Declination* ° ′	*Right Ascension* h. m.
Aldebaran . . . . . (a)	1.1	291 52	N 16 23	4 33
Regulus . . . . (b)	1.3	208 41	N 12 15	10 5
Spica . . . . (c)	1.2	159 28	S 10 51	13 22
Antares . . . . (d)	1.2	113 33	S 26 18	16 26

The Air Almanac lists the positions of 55 stars that may be used in navigation. These four just given are shown on a special daily position strip that helps the avigator locate these stars and shows the relative positions of the planets, moon, and sun.

Two other lines of reference on the celestial sphere are used in obtaining position. Since earth measurements are made from Greenwich longitude, and celestial measurements from the vernal equinox, the two must be tied together. The *Greenwich hour angle* does this. The GHA (as it appears in the tables) is the difference in longitude between the Greenwich Meridian (0° Long.) and the longitude of a point directly beneath the celestial object being observed. The *local hour angle* is the longitudinal difference between the longitude of the observer and that of some point directly beneath the celestial object observed. The diagram makes the relationship of these angles clearer.

By now we have accumulated all the raw material needed in establishing lines of position. The observer gets down to work and takes his observations. This may be done in several ways and the techniques and corrections in shooting the sun and moon are different from those of stars. For the sun and moon, the correction is made so that the altitude is that of the center of

that body—this *semidiameter correction* is not necessary for stars. Tables help in reducing the corrections to simple arithmetic.

The accurate clock or chronometer carried for navigation purposes is set to give Greenwich time. This time is checked daily by radio signals so that a high level of accuracy is maintained. The observations are made in rapid succession. The Greenwich time is recorded in hours, minutes, and seconds and the observed height of the star in degrees and minutes. Ten observations are usually made. An average of the time and observations is obtained and these average figures are used in the computations.

To simplify his work even more, the avigator frequently makes use of a standard work sheet for making his computations. With this, he goes from one step to the next in a fixed progression, and the possibility of arithmetical errors is greatly reduced.

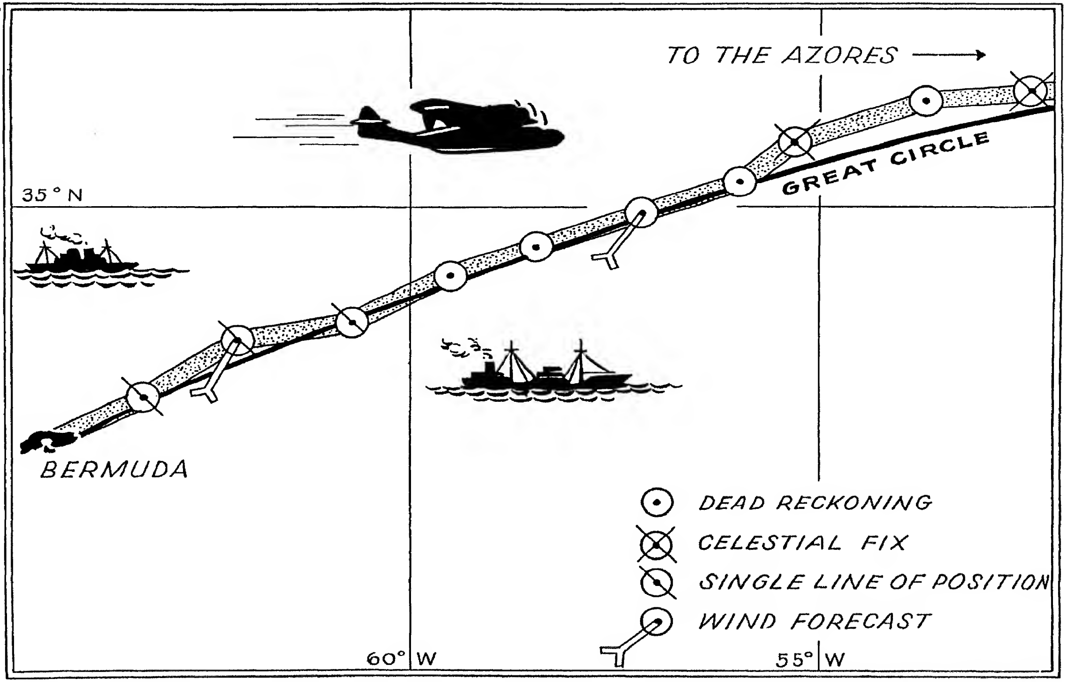
Once the corrected altitude is obtained, the observer next uses the tables of the Air Almanac to obtain the Greenwich hour angle (GHA) of the star at the Greenwich civil time of the observation. The observer has assumed his position or knows approximately from dead reckoning where he should be. Using his assumed position and the Greenwich hour angle (GHA) he obtains the local hour angle (LHA). From the Air Almanac the observer also obtains the declination of the star.

Using the line of position table in the Air Almanac the avigator obtains an A value from the table for his local hour angle

(LHA) and a B value for the star's declination. These values are used with another value, K, that abridges the work. With proper addition and subtraction and further use of the table, an azimuth value is obtained. The azimuth is the angle between a great circle and a meridian. It is the same as a bearing. A second observation on another star and computation will give the second bearing needed to determine the fix. Actually, the plane has moved along its course while this work is being done, so dead reckoning adjustments are needed to establish the plane's position accurately.

Celestial navigation is much harder to explain than it is to practice. After the avigator has worked out sample problems for himself he quickly gets the hang of the system. The work can be reduced somewhat by computing devices that shorten the arithmetic. A further aid is the use of the North Star as one of the two stars observed. Because the North Star is only a bit over 1° from true north, there are special tables in the Air Almanac that make it quicker to obtain a line of position from Polaris than from other stars or the sun.

For long trips, much of the computation is done in advance. The pilot estimates, by dead reckoning, the position of his plane at scheduled intervals. The altitudes and azimuths of selected celestial bodies may then be computed for the time and position predicted for the course. During the actual flight, observations are made as near the time and place predicted as flying conditions permit. If the precomputed data have been plotted, corrections can be quickly made that will give lines of position



Courtesy of Pan American Airways

THIS DETAIL OF A PAN-AMERICAN FLIGHT SHOWS THE NAVIGATION CHECKS ACTUALLY USED DURING THE FIRST PART OF A FLIGHT FROM BERMUDA TO PORTUGAL

and a fix with a minimum of effort. There is no real saving in this method, except that much of the work can be done in advance before the start of a flight.

Another important aid in celestial navigation is the use of *star altitude curves.* These curves have been plotted for some of the brighter stars and hence the method can only be used at night. Rapid observations (within one minute) of the altitude of two stars must be made. Then, if the correct star time (Greenwich sidereal time) is known, latitude can be read directly from the graphs. The use of local time and Greenwich time gives a difference equal to the longitude and hence a fix is quickly made.

Celestial navigation may sound complicated. It may seem just a mass of additions, subtractions, and corrections, one after the other. The pilot who really understands the earth and stars sees the logic of the steps in a celestial navigation computation, but probably did not get it straight the first time either. There is a certain disadvantage in using the short cuts of tables because one is likely to be vague about the steps circumvented by the short cuts. If you have the time and ability, there is nothing like tackling celestial navigation from its mathematical basis.

Celestial navigation—all navigation for that matter—requires practice and more practice. The best you can get from an elementary account, such as this, is an idea as to what is involved and how the process of avigation goes on. Even the knowledge of avigation is insufficient without the skill that comes from flying experience. This practice cannot be obtained

by reading, but you can get some idea of the practice of aviga-
tion as it is constantly used in transports and bombers, airliners,
cargo and private planes.

17

ON THE AIRWAYS

THE TEST of a pilot's knowledge of avigation is his flying. No one really understands charts, instruments, and radio beams till he has had experience with them in the air. A poet once said that words have wings. Perhaps so. If the words of this chapter will help you get off the ground, then he may be right. So permit these words to take you along on a trip with an experienced pilot to see how he navigates.

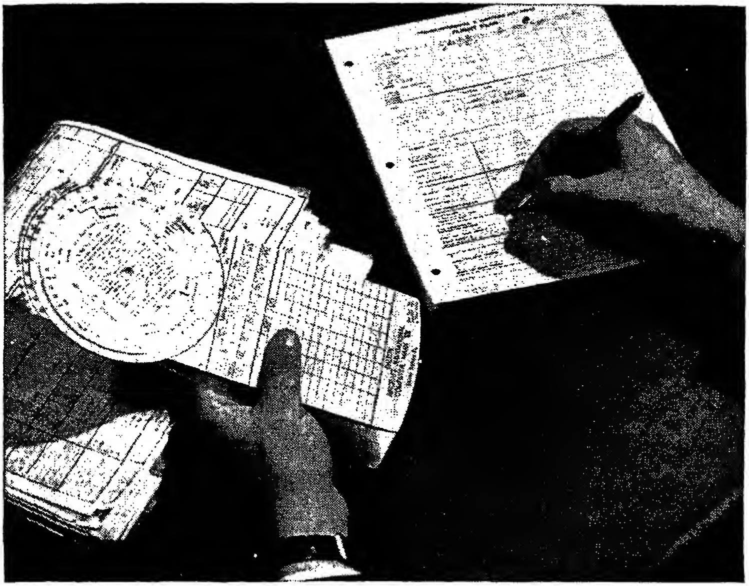
This is not easy to do, as the cockpit of airline planes is completely closed to passengers, but perhaps we can get special permission from TWA and the CAA to watch over the pilot's shoulder on a short flight. Let us tag along on Flight 21 from New York to Philadelphia. It's a short hop—not even a real sample of an airline flight, but it will give us plenty of time to see what is going on. Even though Philadelphia is a scant hundred miles from La Guardia Field, the TWA flight officers will be using all the methods and equipment used on longer flights, except perhaps the automatic pilot. This help isn't usually needed on a forty-five minute flight.

The Captain and First Officer get to the field at least an hour before their scheduled take-off. They come unless the weather is so bad that they have been notified the flight is canceled—and

that is not very often. There may be doubt when the Captain leaves his home. If so, he gets all the weather data as soon as he reaches the airport. He talks the problem over with the Flight Superintendent who is also an experienced flier. Unless they both agree that the flight can go through safely the plane does not leave. Sometimes these decisions cannot be made till the last minute. A final bit of weather news may decide the issue. While the company does everything possible to keep on schedule it always considers safety more important than punctuality.

Whatever the weather, the First Officer and Captain consult the meteorologist who gives them the latest data. Even before the flight plan is made, it is necessary to know from the meteorologist such facts as wind direction, speed, optimum cruising altitude, temperature, as well as possible storm conditions. With these data the First Officer makes out the flight plan. This routine is part of his training. The Captain checks and approves the plan but the First Officer does the work.

To make the plan, the First Officer uses his "Brains." That's what pilots affectionately call their navigation kit containing charts, computers, data sheets, and current government notices to avigators. The First Officer knows how to break the flight up into blocks. He knows the stops, distances, and most of the data about the plane. From his data sheets he finds the scheduled time for the run—in this case only 47 minutes. With this flight plan form before him he starts to fill in the blanks—flight number—plane number—from—to—departure time—. He gets into arithmetic almost immediately. From the 47 scheduled



Courtesy of Transcontinental and Western Air, Inc.

THE FIRST STEP IN ANY AIRLINE FLIGHT IS THE PREPARATION OF A DETAILED FLIGHT PLAN

minutes he subtracts 7 minutes for taxiing at take-off and landing—this is the same for all planes and flights. For the short flight to Philadelphia our pilot decides to fly at 4,000 feet. He would go much higher on longer flights. Going west he must fly at even thousand foot levels and going east at odd.

He next consults the tables that show the rate of climb for the DC-3. At La Guardia Field he should allow 9 minutes to climb to 4,000 feet. By the end of the climb the plane will be 18 miles from the airport. This leaves only 31 minutes to cruise

about 80 miles, without allowing for any possible delay in landing at Philadelphia. A cruising speed of 155 miles per hour should take care of this. But there is the wind to consider. Will it be a help or a hindrance? The First Officer looks at his weather data, twirls his computer dials, and comes out with an answer—to do 155 mile ground speed he'll have to maintain 163 mile air speed because of the wind velocity and direction. A pilot flying east is more likely to have a helping tail wind because of the general wind direction of our latitude.

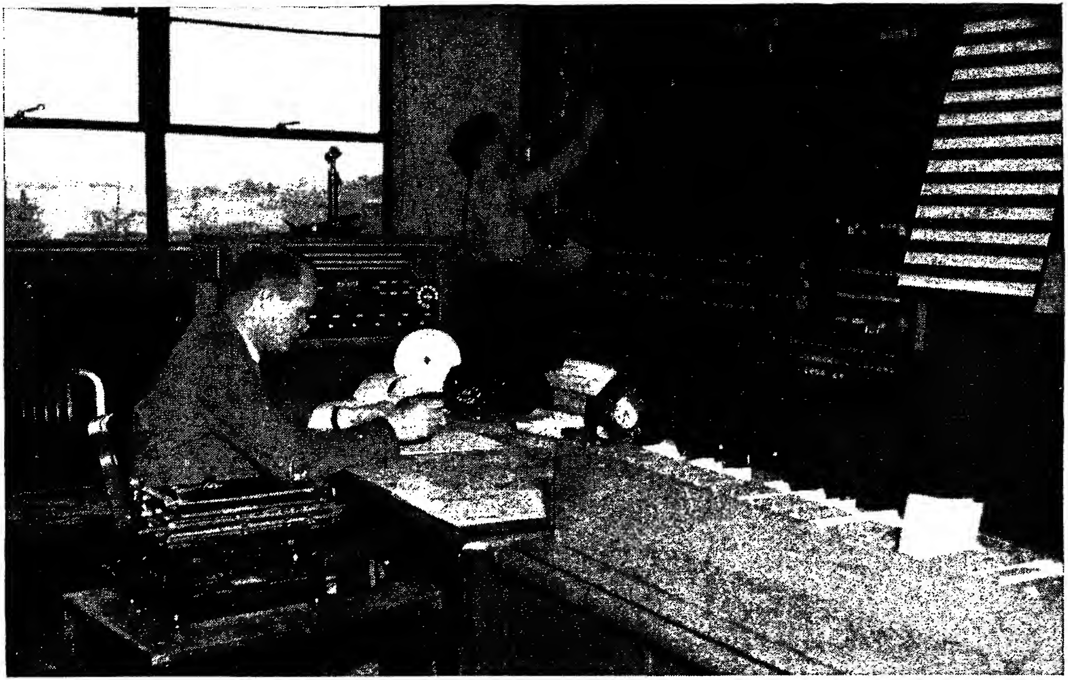
All these figures and calculations go into the flight plan so that the record is down for good and for all. Next our pilot computes the power needed to push the plane along at a 163 mile air speed. On the big DC-3 the powerful motors can furnish 1,200 horse power each, but they can only run at this top speed for a short time. During the take-off, when most power is needed, the plane will use the full 1,200 horse power—but only for a minute or two. For cruising, 500 to 625 horse power per engine is used. Again the computer spins around and our Officer quickly discovers how much gas he will need—it turns out to be 70 gallons—enough to take an ordinary auto to Philadelphia and back six times.

The First Officer knows that his plane can carry up to 800 gallons of gasoline. He won't carry that much on such a short hop, but he will carry far more than 70 gallons. In making the flight plan, the Officer must select one or more alternate airports at which to land if landing is impossible at Philadelphia. Perhaps the plane may have to continue to Baltimore or Washing-

ton. The CAA regulations require that the plane carry enough gas to reach the farthest alternate landing field with a final reserve sufficient to keep it in the air for 45 minutes after that. So our pilot may carry over 200 gallons with him on this trip. On longer flights the pilot would consider his load, passengers, and weather in estimating his fuel consumption.

When the flight plan is finished and checked by the Captain, it goes to the Flight Superintendent who keeps one copy on file and returns one to the Captain. An Airway Flight Plan Data Sheet goes to the Airway Traffic Control who will give the plane permission to fly this particular route. The data sheet is a summary of the flight plan listing all check points and time. The Captain then gets his clearance papers. This is his official permission to take the trip and indicates that everything is in readiness. The plane is now in the pilot's charge till the trip is over. The mechanics have checked the plane and have given their O.K. on the clearance papers. The meteorologist's reports are attached and with the Flight Superintendent's signature the plane is ready to take off.

The Captain and First Officer pick up their plane at the hangar about twenty minutes before the time of departure. They settle down in the cockpit and park their "Brains" alongside them. Before they start the engines, the Captain gets out his check list. There are 18 items to be checked even before the motor is started. The First Officer reads them off. The Captain touches, checks, or sets each instrument, dial, or control. The fuel, carburetor, propeller, brakes, and feed valves are checked.



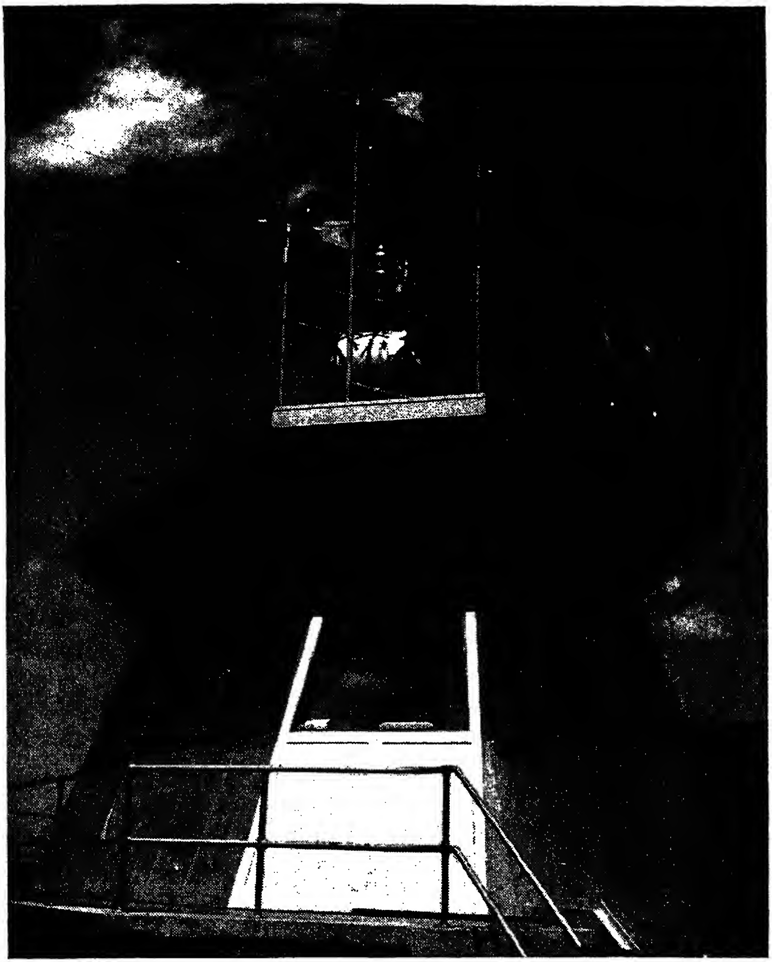
Courtesy of Transcontinental and Western Air, Inc.

THE FLIGHT SUPERINTENDENT ISSUES CLEARANCE PAPERS FOR EVERY FLIGHT ON THE AIRLINES

The automatic pilot must be off, the radio turned on. Check on landing gear. Check on lights. Check on heaters. Check and check again to insure perfect safety.

There is a radio check to establish communications. Over the radio the Captain asks permission from Airway Traffic Control to taxi to station. Back comes the answer with a coded message of barometer setting and wind direction. The code is a wartime precaution and until the airways are safe all messages of possible value to the enemy are given in code. The motors roar and the big plane swings out of its hangar down to the loading platform. The motors are off again while baggage, mail, and passengers are loaded. A last minute message gives the Captain the total weight of his loaded plane and the weight distribution. This is important, as the center of gravity of the plane must fall at the correct position to insure easy flying. The men who load the plane distribute the weight in exactly the right way. Soon the motors are roaring again. The Captain asks permission to taxi to the runway.

The Captain takes his instructions from the Airway Traffic Control who have copies of every flight plan. They know what planes are coming and going and exactly where they are. The answer comes back "O.K., TWA flight 21, wind northwest, 35 miles per hour, use runway number 5." The wind direction and velocity are in code. The big plane taxis out to the end of the runway. It is lined up ready to go, but not yet. Another check list appears. Eight more checks, including flight controls, gyrocompass, and artificial horizon, must be made. The tail wheel is



Courtesy of Transcontinental and Western Air, Inc.

FROM THE CONTROL TOWER AT LA GUARDIA FIELD PLANES ARE DIRECTED OUT TO THE MAJOR AIRWAYS OF THE UNITED STATES

locked and with scarcely any noticeable change the plane is in the air.

The Captain calls back to the control tower giving his time of take-off. In reply "Airway Traffic Control clears TWA Flight 21 to La Guardia control boundary, cruise 4,000 feet, no traffic reported." The message is confirmed and the Captain switches over to the company wave length and gives his time off ground. The company checks with the Airway Traffic Control and the message is relayed all over the country. From La Guardia to Philadelphia to Washington to Chicago and Kansas City—every control tower knows that Flight 21 is in the air.

The plane is in the air. The Captain is completely in charge. He can navigate by any method he chooses. Whatever he does he is responsible and is held strictly to account. If he wants to alter his course he can do so, but he must notify the company and ATC. Naturally the Captain does not rely solely on one method of avigation. As he left the runway he picked up the west leg of the La Guardia radio beam and has set his course along it at 300°. He checks his compass and has set his directional gyro. He watches the altimeter show his steady climb.

The plane crosses Manhattan north of Central Park. The Captain sees the huge buildings to the south and the Hudson River straight ahead. By the time he has climbed to his scheduled 4,000 feet he is over New Jersey at the intersection of the Newark and La Guardia beams. He changes his course and swings to the south. The dial of the directional gyro shifts slowly. The Captain settles on a 238° course that will soon bring

him directly over the Newark Airport.

You may have noticed that no time of departure for this trip was given. Normally departure time is one of the first things that goes on the flight plan. But this is a very special trip and for your particular benefit it may be necessary to change both the time and the weather during this scant half hour in the air just to let you see the corresponding changes in avigation.

It can remain a bright clear afternoon while the Captain swings south from the La Guardia to the Newark beam. He is making a 62° turn and as the ship swings he watches both his compass and directional gyro, judging the turn mostly by the latter. He does not watch the bank indicator intensely. With all his experience, correct banking on a turn is second nature. But he does see it out of a corner of his eye as he watches the directional gyro. By now we are ten minutes out of La Guardia Field and close to Newark. The on-course signal is loud and clear in the headphones. It is broken every minute by NK in code identifying the Newark radio range station. As we pass over Newark the signal fades out in the cone of silence and the special receiver picks up the Z signal that makes certain the pilot has hit the cone.

The Captain throws his radio switch and, calling La Guardia Field, reports Flight 21 over Newark. He gives the time, altitude, and estimated time to his next contact point—Metuchen, N. J. There is little more to do now. The course holds straight for Philadelphia. The Captain watches his instruments, glances down to notice the Edison Memorial, the Princeton Stadium,

locked and with scarcely any noticeable change the plane is in the air.

The Captain calls back to the control tower giving his time of take-off. In reply "Airway Traffic Control clears TWA Flight 21 to La Guardia control boundary, cruise 4,000 feet, no traffic reported." The message is confirmed and the Captain switches over to the company wave length and gives his time off ground. The company checks with the Airway Traffic Control and the message is relayed all over the country. From La Guardia to Philadelphia to Washington to Chicago and Kansas City—every control tower knows that Flight 21 is in the air.

The plane is in the air. The Captain is completely in charge. He can navigate by any method he chooses. Whatever he does he is responsible and is held strictly to account. If he wants to alter his course he can do so, but he must notify the company and ATC. Naturally the Captain does not rely solely on one method of avigation. As he left the runway he picked up the west leg of the La Guardia radio beam and has set his course along it at 300°. He checks his compass and has set his directional gyro. He watches the altimeter show his steady climb.

The plane crosses Manhattan north of Central Park. The Captain sees the huge buildings to the south and the Hudson River straight ahead. By the time he has climbed to his scheduled 4,000 feet he is over New Jersey at the intersection of the Newark and La Guardia beams. He changes his course and swings to the south. The dial of the directional gyro shifts slowly. The Captain settles on a 238° course that will soon bring

him directly over the Newark Airport.

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and other contact points as he passes.

While the trip is going so smoothly, let's see what would happen if we had left at night instead of on a clear afternoon. There would be very few changes. The airport would, of course, look different with lights marking the approaches and the runways. The plane too would have its landing lights on during take-off and its navigation lights would burn continuously. The cabin would be illuminated but not the cockpit. The instruments would glow in their weak green light but all else would be dark. There is no glare to interfere with the pilot's vision. As we take off we would see the powerful 13,000,000 candlepower beam at La Guardia sweeping the horizon with its green course lights indicating a landing field. In the air we pick up the light on the Empire State Tower and the beacon above George Washington Bridge. Patterns of light mark the parkways, bridges, and factories that run twenty-four hours a day. All these are familiar to the pilot. Some of them are out for the duration. The reflections from the East and Hudson Rivers show up easily. Headlights of cars dot the roads and on clear nights railroad tracks can be seen. The Captain uses his radio and instruments, but as long as he can see ground he makes as much use of visual aids as he would in daylight flying. There will always be at least one beacon visible, swinging in its path across the sky. At Newark, Metuchen, Trenton, and a half dozen other places these lights help check the pilot's course.

Now let's blacken the sky, pour down the rain, and roll the thunder. We cannot make it too bad or the flight would be can-

celed, but on an early summer evening it is quite possible to leave La Guardia in clear weather, run through a thunderstorm, and put down at Philadelphia in a pouring rain. The thunderstorm will be no surprise. It will be there in the weather report—everything about it. The Captain might choose a higher flying altitude to start, or he may drop lower as he hits the storm in search of less turbulent air. He'll watch the sky carefully, looking for breaks in the overcast. Flying may be rough and the passengers will notice it despite extra care at the controls.

Under such conditions the Captain doesn't bother looking outside. All his attention is concentrated on his radio and avigation instruments. He watches his radio compass and directional gyro and artificial horizon. The storm may affect the radio compass, so he keeps a constant check between radio compass, magnetic compass, and directional gyro. Static may interfere with his radio beam reception. So he watches all instruments more closely. He knows from his flight plan where he should be. If the wind has changed, he makes allowance, perhaps giving the plane a bit more power. He may call ahead to Philadelphia for an up-to-the-minute weather report.

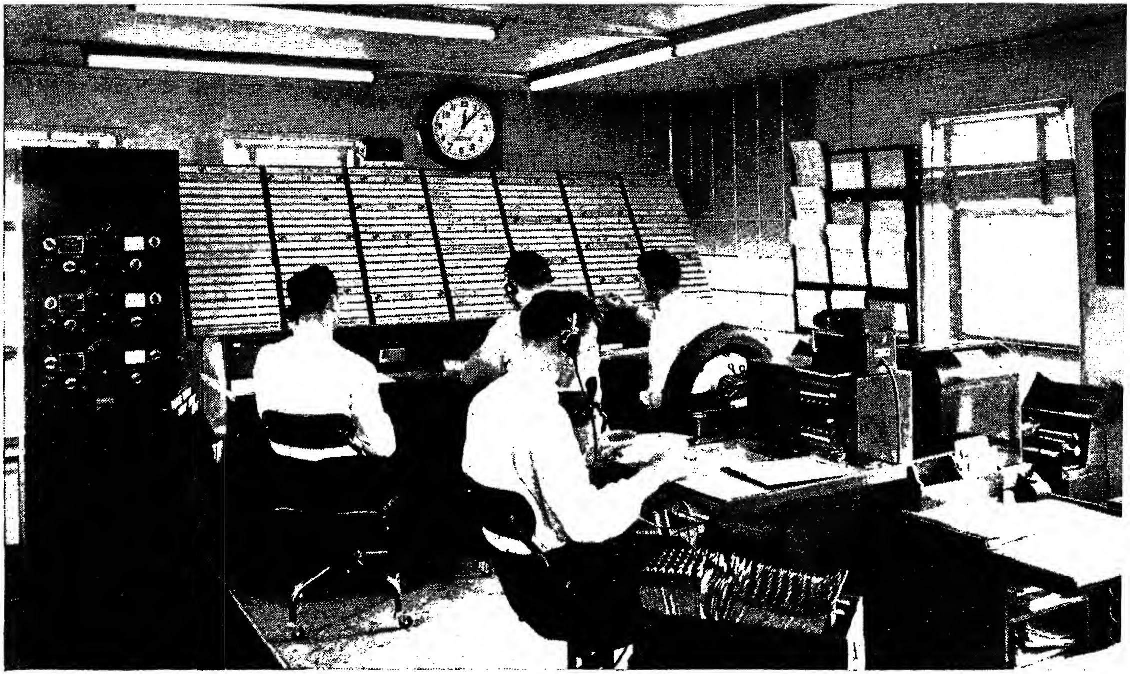
In flying the overcast, the Captain will change direction as he nears Philadelphia. Here the paths of north- and south-bound planes converge. With low visibility this might prove dangerous. Therefore, when the plane is over the little town of Yardley near Trenton, N. J., the Captain swings his plane northward again from the 238° to a 260° course. This carries him north of Philadelphia till he hits the north leg of the Philadelphia

beam; then he swings south, 180°, and follows the beam directly to the airport.

Over Metuchen the Captain again reports his position, altitude, time, and expected time to Philadelphia. Soon after he switches over and calls the control tower at Philadelphia reporting TWA Flight 21 ten miles from the airport. The control tower gives the Captain his altimeter setting and, when the plane is over the Philadelphia field, also gives wind direction and any special landing instructions. There may be another plane coming in, so TWA Flight 21 will circle the field at 1,000 or 2,000 feet till permission is granted to land. As he approaches for landing there is another check of instruments and controls—10 points this time and 6 more checks after the landing gear is lowered.

The trip is over but not quite. Before the Captain and First Officer leave the cockpit there is a final check. Then there are reports to be filed. A barograph record kept by a sealed instrument has automatically recorded the plane's altitude during every minute of the trip. This record is filed with the CAA. If the Captain has changed from the altitude of his flight plan, he will have to indicate the reason on the barograph card.

Such a short flight is not completely typical. The Captain has kept the controls all the way. On longer flights the First Officer might take over and fly a while or the automatic pilot would do the work for both. The First Officer keeps the log of the flight, radio messages sent and received, contacts, and time. The records must be complete. If the First Officer is at the controls, the



Courtesy of Transcontinental and Western Air. Inc

AIRWAY TRAFFIC CONTROL KEEPS TRACK OF ALL PLANE MOVEMENTS IN AND OUT OF THE MAJOR AIRPORTS AND ALONG THE AIRWAYS

Captain keeps the log.

In this flying the experienced Captain has used his instruments and aids as a trained chef uses the ingredients of a soup or salad. All the ingredients of good flying are blended together, till the flight is so smooth that the passengers don't notice it at all. That is the height of good flying—to make the passengers oblivious of the fact they are tearing along toward their destination at 150 or 200 miles per hour. The pilot who uses his avigation so that his flying is safe, smooth, and on schedule is master of the air.

18

THE CIVIL AERONAUTICS ADMINISTRATION (CAA)

MOST of us do not appreciate the extent to which our actions are controlled. Take driving, for instance. In order to drive a car you must pass a test and get a license. The car must have a license, too, and in some states it must be inspected regularly. As far as most of us are concerned that is all the contact we have with the state when we drive a car—unless we are so unfortunate as to meet up with a state trooper when doing 60. The state control of cars, traffic, and roads goes much further, but we are not often brought up against the facts. It took a war with gasoline and rubber rationing to illustrate how complete government control can be.

In flying it is quite another matter—government control is in the picture from beginning to end. In this case it is the federal government, not the state. But the federal agency that controls and promotes flying is thorough and efficient. You cannot take up a plane, much less navigate one, without proving your fitness first.

All flying in the United States is military or civilian. The military flying is under the direct control of the Army and Navy. These organizations own their own planes, train their

own pilots and navigators, maintain their own airports and weather stations. In short, they are completely self-containing as all good military forces should be. The non-military flying is just as well organized and in its own right has achieved as much success as the Army and Navy fliers have. During wartime civilian flying has been greatly restricted, but everyone expects that in the near future more people will be flying than ever before. Then the civilian side of flying will be important again.

It is only a matter of twenty years ago when flying was entirely an individual matter. You bought a plane, took lessons if you wished. Whenever you wanted you went up, and if you crashed so much the worse for you. There were so few planes and so flew fliers in those days that it did not really matter. The accident rate was high. But, after all, flying was known to be dangerous and only a dare-devil would go in for that sort of thing.

1926 marked the beginning of government regulation of flying. In that year the Air Commerce Act was passed. This led to the formation of the Aeronautics Branch of the Department of Commerce. In 1934 this division became the Bureau of Air Commerce. The next step came in 1938 with the passage of the Civil Aeronautics Act. This set up the control of the air in its present form.

Names and dates don't mean very much. What happened is the important thing. From the time of the Air Commerce Act in 1926 things began to happen. They have continued at a

faster and faster pace ever since. In 1927, 1,400 miles of airways were surveyed and equipped with rotating beacons. This, plus some mileage that had been developed by the Post Office Department for air mail use, made a total of just over 4,000 miles of airways in the United States.

Today there are over 30,000 miles of lighted airways in the United States alone. There are airways in Alaska and in our island possessions and other international routes have been built with our aid and co-operation. Over these routes, in 1941, more than 3,000,000 passengers traveled and over 16,000,000 pounds of air express. The fifty or so airport traffic control towers handle over 2,000,000 plane movements a year on such a schedule that planes can safely land and take off from two to five minutes apart. The war has curtailed this growth, but only temporarily.

To get some idea about the job of controlling civil aviation in a country as great as ours, just consider what has happened during the past ten years. Remember that by the end of 1931, aviation was no longer in its infancy. Lots had happened since the days of the Wrights, Langley, Lilienthal, and the other pioneers. The First World War had made flying practical. The Atlantic had been crossed several times and planes had flown around the world and over the Poles.

The civil airways were started in 1927. By the end of 1931 there were 17,000 miles of lighted airways and ten years later this had almost doubled. There were 31,000 lighted airway miles in 1941. During the past year the government spent $548

to maintain each mile of airways and has engaged a staff of nearly 4,000 men to do the work. The men doing maintenance work at hangars and along the airways for the airlines number nearly 5,000 as compared to 1,500 in 1931.

Civilian planes have more than doubled in ten years, with a present total of nearly 22,000. These planes consume about 25 million gallons of gasoline annually, with which they fly about 300 million miles. Eighty-two thousand people are licensed to fly. That is double the number licensed in 1940, which in turn is double the number for 1938.

Strangely, the number of airline transport planes has actually decreased from 490 to 365 in ten years. But the new planes have three times the passenger capacity and 50% more speed than the planes ten years back. With all the increased mileage flown, the number of accidents has dropped steadily. In 1931 there was a fatal accident for every three million miles of flight. Now the rate has dropped to one fatal accident in thirty million miles of flying. Air mail and air express carried over the airways have showed constant increase; about twenty times as much express is carried now as ten years ago.

The personnel employed by airlines has increased from 5,600 to 23,900 including a jump of from 694 to 2,337 pilots and co-pilots. Over twice as many mechanics are now employed. The Army and Navy have trained airmen so fast that it is impossible to get a total of all those now engaged in operating and maintaining planes.

As for avigation, we see the same picture of progress. In ten

years the number of radio range stations has increased from 47 to 291. The weather reporting teletype system had 13,000 miles of wire in 1931 and ten years later had 29,000. There are now 70 ultra-high frequency range stations where none existed in 1939. There are 188 fan markers. None existed in 1938. Last year there was only one instrument landing airport. Now eight more are under construction and plans include a total of 21 before the year is out.

To light the airways there were about 2,000 beacons in 1931 and 3,000 ten years later. There are now 336 intermediate landing fields for emergency use. To maintain its airway system cost the federal government over eighteen million dollars in 1942.

The purpose of these figures is not merely to recount the growth of aviation in this country, but to help you appreciate the extent of the movement in which you may soon have your part. In 1939 there were about 23,000 private pilots. In 1941 licenses had been granted to nearly 100,000 with many more in active training. These figures are something that every potential avigator should keep in mind. We are headed for a time when literally millions of people will fly—a time when avigation will take on new meanings and responsibilities because of the new ways in which it will be used.

This rapid growth of aviation is no mere accident. One force that pushed flying forward with vigorous steps is the Civil Aeronautics Administration, created by Congress in 1938—descendant of the Aeronautics Branch of the Department of Commerce.

You can't afford *not* to know about the Civil Aeronautics Administration (more usually abbreviated CAA) if you are going to fly. Furthermore the story of the CAA is in a large part the story of flying in this country. Every chart, beacon, radio range, and airport is a visible sign of the work of this department.

Each civilian plane that flies overhead is licensed by the CAA and so is the pilot in charge. Many of the pilots received their entire training under the CAA program, at CAA training fields, under CAA instructors. As they made progress and passed CAA tests, they were able to obtain more advanced pilot's ratings. The CAA does not merely license a pilot but follows him closely during his entire career in aviation. His record, logs, time in the air, physical condition, and any other pertinent facts are always available to the inspector, who not only issues licenses but takes care of their periodical renewing.

The same is true of the plane. The CAA is in the picture even before the new plane is off the blueprints. No hare-brained designer can patch up a plane and pass it off on an unsuspecting purchaser. A plane cannot be manufactured till the plans have been checked and rechecked by CAA experts of the Aircraft Engineering Division. From the blueprints and test data submitted by the designer or manufacturer these specialists can usually tell whether a plane will be safe and how it will act in the air. If they have any doubts, they may order special tests of the plane or any specific parts they believe to be weak. This process either results in approval or recommendations for alteration and improvement—with further tests before approval is

granted.

The approval by the Aircraft Engineering Division is not a final O.K. It is the first step. The manufacturer can then go ahead with his plans. But before the plane is put on the market, the engineering inspectors of the CAA give an actual model a thorough going-over. These engineering inspectors—more familiarly known as CAA test pilots—test everything that flies. The plane is put through its paces—all aspects of speed, maneuverability, and safety are checked in the air. When the test pilots are through, they'll know if there is any possibility of a plane pulling off a wing in a dive or if a "flutter" of rudders or ailerons will throw it out of control. The CAA engineering inspectors take up not only small civilian planes but transports as well. All the big commercial planes right up to the Clippers have passed through CAA hands. Military planes are also tested —not because CAA approval is necessary for the Army or Navy but because the manufacturers want this approval so that the planes can be converted to civilian use when fewer are needed for military purposes.

With a completion of these tests, the CAA issues to the manufacturer a certificate attesting to the airworthiness of the particular type and model plane. These planes can now be sold, as long as the manufacturer adheres to the design and specifications of the approved model. CAA factory inspectors stationed at all the major aircraft factories constantly check to see that these conditions are met. Manufacturers are glad to co-operate because they realize that the purposes of the CAA are in the best

interest of aviation. Large manufacturers run their own tests and carefully inspect their planes at every step in their construction. This close co-operation with the CAA results in high efficiency in plane production and an absolute minimum of structural failures in the finished products.

The pilot receives just as much attention from the CAA as the plane does. All flying schools must have a CAA license—and so must the instructors. This protects the ambitious, but ignorant, embryo flier from operators of fly-by-night schools, fraudulent study-at-home schemes, and from well-meaning but badly-trained instructors. The ground course must meet CAA requirements and CAA flight inspectors of the General Inspection Division examine applicants for pilot's license. There are over a thousand of these inspectors and their assistants, who constantly cover all the airfields and schools, giving examinations and advice to pilots in training.

To secure his pilot's license, the applicant must have training, experience, as reckoned by time in the air, and must be able to demonstrate to the inspector his ability to handle and maneuver a plane. He must also show his familiarity with airplanes and their equipment, radio, meteorology, navigation, and Civil Air Regulations.

Other divisions of the CAA do work that is less familiar but of equal importance. One division is in charge of airlines. The inspectors see that transport planes are regularly and properly maintained. They check the vital radio instruments and carefully consider all matters of airline operations that might affect

the safety of the planes and the lives of the passengers. Here too there is the closest co-operation between the airline officials and the CAA, so the work is not that of routine inspection but of two groups working together for better aviation.

CAA research is more than one step ahead of the best practice in flying. The Technical Development Division tackles all those problems that give the pilot his headaches. New instruments, new techniques and devices are constantly being perfected. The whole instrument landing development, which is now being installed in the larger airports, is one example of the contributions of CAA research. There are still other developments in the use of ultra-high frequency radio waves that may revolutionize avigation. CAA scientists are working on the problem of airplane fires and are developing a carbon dioxide system that will extinguish the roaring flames of burning gasoline and oil. This division is also working on systems to keep a photographic record of aircraft performance including an automatic log of the flight. New types of charts and maps are devised for aeronautical use. When the experiments seem drawing to a successful close, the new instruments or methods are given complete practical tests at the CAA experimental airport station at Indianapolis, Indiana.

The results of technical investigations are published in one or more of the publications of the CAA. The Safety and Planning Reports cover such topics as "Report on Cone of Silence Tests at Knoxville, Tenn." and "Analysis of the Aviation Medicine Situation." Among the Developmental Reports will be found

publications on ultra-high frequency aircraft receivers, airport zoning legislation, and aeronautical lighting. There are other publications giving statistics, tabulations, and data about all phases of aviation. The Civil Aeronautics Bulletins are written to give direct help to the pilot. These widely read publications deal with meteorology, aerodynamics, radio, engines, navigation, etc. Twice a month the CAA publishes its official journal through which all pilots, and others interested in flying, can have the latest news and information from official sources.

CAA publications come from the Office of the Information and Statistics Service—the fact-dispensing division of the organization. Facts rolling from the mailing rooms of this division are essential to safe flying and to the progress of avigation. From this office come the "Weekly Notices to Airmen," which will be found posted on the bulletin board at every airport. These bulletins contain information of current importance to fliers; a warning that the runway of a certain airport is under repair; a notice of a new beacon being erected; or the change in wave length of a radio signal. There are other pamphlets and bulletins dealing with all subjects on which pilots want and need information—on the load factors of planes; on number and kinds of accidents; on the CAA training program. There are directories of airports, trade directories, lists of publications, and much more.

The Information Service answers questions, too—thousands and thousands of them. Most of these come from pilots or people really interested in aviation who want data about all

sorts of things. Then there are also cranks with odd ideas, complaints, and queries. The Information Service does whatever it can to help all those who inquire. If they cannot answer your question, they will try to locate someone who can.

From this office also come many of the facts about flying you read in papers and books. Data about pilots and planes are recorded on an ingenious statistical card by means of holes punched in certain standard positions. A hole in one spot indicates that a pilot is a male—a nearby spot indicates female. Another hole indicates commercial license or transport license. An electrical machine assorts these cards faster than the eye can follow. Running the cards through the machine will separate and count all cards of commercial pilots of ten years' experience or all cards of civilian pilots who have had an accident during the past year. In this way accurate, important information is available immediately to any person or organization that needs it.

The importance of the CAA is quite evident. The ability to fly is a prerequisite to avigation. In its control and development of flying from the ground up the CAA has done much to make avigation safer and easier. The program to "Keep 'em flying" takes in everything from the legal end to the development of avigation aids. Since 1939 the CAA has led a new and vital movement in aviation. That winter witnessed the inauguration of a nationwide training program for young pilots—which sooner or later will directly affect most young people in this country.

19

AVIGATION AND YOU

THIS is a good time to ask yourself, "What does flying and avigation mean to me; what *will* it mean to me? Why have I taken the trouble to read through a book on air navigation when there are plenty of aviation stories crammed with excitement and adventure?" I can't answer these questions for you, but I suspect that your interest in flying is deeper and more sincere than that of people who are only concerned with adventure. You are probably interested in the true side of flying; the side that means hard work and study, but that also holds the prospects of a fine career and the satisfactions of a job well done. It has to include that last point because no job in aviation—especially that of the pilot—can be done in any way but well.

Flying is an occupation for young people. It is one of the few major industries where youth is an asset. The one universal opinion of those who have made flying their life work is that it is never too early to begin. This doesn't mean that all the "old folks" are out. There will probably be more and more people, who no longer consider themselves young, who will take to the air. With safer, better, and cheaper planes it is quite

possible that grandpa will soon taxi his sport plane out of the family hangar and fly off for a winter vacation in Florida or California.

But the important flying of big transport and cargo planes, of planes for the Army and Navy, that will be the job for young people. Even now you can see how the situation stands. At the age of thirty-five most doctors are just getting their practice established after long years of medical school and internship. At thirty-five many lawyers are just settling down after years of study and working their way up through an overcrowded profession. In business, industry, and commerce progress is relatively slow. The person who has the ability and who fits the job may show how good he is when still young, but there is not much chance that he will be up at the top of the ladder by the time he is thirty-five.

In aviation it is different. There is every chance of being right up near the top long before you reach the middle thirties. For First Officer training in the TWA the age limits are from twenty-one to thirty-two. If you have the ability and qualifications to start near the minimum age level, you can go far by the time you reach thirty-five—and many TWA fliers have. Let's take just one example to make this clear.

I'd like you to meet Ray Wells who, at this time, is Chief Pilot of the Atlantic Division of TWA. The job is one of heavy responsibility. It must be when TWA covers nearly twenty million miles a year and carries nearly half a million passengers. Even without knowing all the details you can be sure that the

man who is entrusted with the chief pilot's job has gone far in flying.

Ray Wells was born in Duluth, Minnesota, in June 1905. He did not live there long. Ray's mother died when he was seven and he went to live with an aunt and uncle in Missouri. He remembers going to the small country school and doing most of the usual things for boys of his age. He attended high school at Arrow Rock and at Blackwater. There was one more transfer to the Kemper Military Academy from which Ray graduated.

This was not a conspicuous start in life. But most men who have made flying a career have started with the usual unexciting boyhood. And most of them, like Ray Wells, became interested in flying when they were young. Ray had never seen a plane till he was twelve. We had just entered the First World War and he had read of the daring feats of aviators. He cut pictures of planes and fliers out of the papers and saved them. One day there was real excitement. Not one plane but, it seemed, a skyful came over the town. Ray wasn't the only one who stood and watched, and watched. The Gates Flying Circus wasn't anything that would make us glance upward nowadays. But this was back in 1917 and Ray was impressed and excited by the planes. He knew then that he wanted to be a pilot.

In those days being a flier was a dare-devil occupation. It was all right for boys to want to become cowboys, Indian fighters, or fliers, but no one took such ambitions seriously. Ray was sincere. Soon after, he and some friends got hold of a discarded butter churn. This was quite a fancy affair with gears that made

the churn paddles spin around even if the crank was turned slowly. Ray took off the churn paddles and mounted the mechanism on his bicycle. Then he built himself a wooden five-foot propeller. He hooked it up to the gears and was ready to go.

When the churn was cranked hard the propeller spun rapidly. It actually worked. The pull of the home-made propeller was enough to move the bicycle right up the street. This was success, so Ray and his friends went right on to build themselves a real plane. They used their newspaper pictures as a guide. Every bit of stray lumber in the neighborhood found its way to the new machine. The fuselage was 14 feet long—the wings were wired in place and covered with old window shades. The ex-churn and the propeller were attached. Hopefully the pilot and co-pilot got in. They turned and turned the crank till their arms ached, but while the propeller whizzed merrily, the plane never budged an inch. Still Ray Wells wanted to be a flier—an Army flier at that.

Ray went to work after he graduated from Kemper and four years later joined the Army. At 22 he was assigned to the Coast Artillery and was sent to the Philippines. Then he got into the Air Corps as an observer in the Second Observation Squadron. He helped map Luzon and other islands. He was stationed at Corregidor. A friendly sergeant taught him the rudiments of flying and gave him a chance to get experience in the air. But to get a commission as a pilot Ray had to return to the United States and start from the beginning, as a cadet. In 1929 Ray entered Rose Polytechnical Institute at Terre Haute, Indi-

ana, to continue his education, and three years later passed the entrance examinations for the cadet school at Randolph Field. At last he was in flying.

From then on things moved rapidly. Ray Wells had a year at Randolph and Kelly Fields and two years at Mitchel Field. As a second lieutenant he gained experience in cross-country flying. In 1935 TWA offered him a new opportunity. Ray took it. He went through the training course and emerged a first officer. By 1938 he was a captain with full responsibility. The next year he became check pilot and began to give his attention to perfecting the TWA flying personnel. His duties increased. In 1941 he assisted the chief pilot and the year later took on the full duties of that office.

Today Ray Wells is far from being an old gray executive. He no longer plays football but still gets in a lot of hunting and fishing. He's a good amateur photographer and he'd much rather be up in the air than behind a desk. His job is an important and serious one. He supervises all the pilots of his division, checks their schedules, helps select and test new pilots and men seeking promotion. He serves on accident inquiry boards when his men or planes are involved. He gives flight and instrument checks and, if necessary, handles disciplinary problems. Because Ray Wells and all the other flight executives have come up through the ranks there is never any lack of understanding. Each man respects the other and enjoys working with him, from the student first officer to the chief pilot.

Ray spends about half the time at La Guardia Field and the

rest on check flights that keep him flying. He's still learning—how to handle the latest cargo and transport planes and how to use the newest instruments. In fact, Ray is looking forward to the time when there will be even larger planes manned by not just a pilot and co-pilot but by crews of a half dozen or more trained men. He would like nothing better than to command one of these huge skyships—and he probably will before long.

There is no doubt about the future of flying. Thousands and thousands of young people will be making the air their careers. Some will be as successful as Ray Wells—a few more so—and a good many will be disappointed. Luckily for those in the last group, it is now becoming easier to tell in advance whether a young person has the physical and mental characteristics essential to success in the air. A person can get the facts early and can use them to advantage. There is so much to be done in aviation that the would-be pilot with poor eyes may find ground work that will give him just as much opportunity to use his abilities and ingenuity. There are many kinds of aeronautical engineering and mechanical and electrical work where perfect physical condition is not so important.

Just what you can do about avigation depends very much on your qualifications and how hard you are willing to try. Advice is not as hard to give as to follow, so here are some suggestions:

The first advice goes to everyone who wants to fly, in almost any capacity. Keep physically fit. Physical requirements are strict, and purposely so. They stress normal development and fitness. The examining doctors at airlines or at military fields

are not especially interested in strength or in your track or swimming records. They do look for normal sight and hearing, a normal heart that can stand the strain of emergencies. They are interested in good lungs, good teeth, good posture—in all the little things that go to make a person vigorously healthy. The kind of health a pilot needs doesn't come from setting-up exercises or vitamin pills. It usually is the result of an entire pattern of living—living that involves a fair share of sports, of work, of study, of good food, rest, and companionship.

If you have any concern about health, your doctor is the man to talk to. You ought to see him for an examination once or twice a year anyhow. He can give you the kind of help you need, and if you are physically fit, he'll be the first to congratulate you. Frequently minor physical defects can be remedied while they are still minor, and often time works wonders—with a bit of help on your part.

Once we are past the stage of telling people to keep healthy, advice cannot be spread so thinly. If you are in school, or can continue to study, do so. First, keep in mind that no single school subject in itself will make the difference of your being a pilot or not, provided you are fit to do the job. School marks are an index of your intelligence, ability, and habits. Lots of young people do more studying out of school than in school. Many more have the attitude (wrong as it may be) that because they can't see the connection between their school subjects and flying, that schooling isn't worth much. Many a youngster has burned midnight oil over a well-thumbed copy of "True

Aviation Adventures" while his mathematics book remained unopened. This is not the place to preach about school, but if you want to fly, you may as well face the facts. Here they are briefly:

You cannot say just how much schooling is needed for aviation as you can for law or medicine. Aviation is newer and more flexible. A college education is an asset, especially if it has included pertinent courses. For many young people two years of college is sufficient. These may be the first two years of a regular course or the course given at a junior college. Some colleges have a special two-year flight-training program to meet the needs of fliers. It is far better to inquire locally than to accept any general rule. See what educational advantages your community offers. Perhaps there are evening or extension courses that are available. Often there are scholarships or work and study plans, so that additional education does not become a financial burden. In wartime the usual college education is out of the question, but instead there are many new flight training programs on the college level conducted by the Army and Navy.

If you are serious about flying, finishing high school is almost an absolutely minimum requirement. With high school training you have a much better chance of getting on. It may be possible to obtain employment in some of the larger aircraft companies and study in their own schools. These courses are closely related to the work being done and are not the general preparatory courses for a flier. But they are a help and may

be a stepping stone toward the specific thing you want to do. Generally, home study courses taken by mail are a more difficult way to study than in class. Check on all other educational possibilities before trying them. But however you do it, keep on studying.

Some school subjects can be a direct help to the person looking forward to flying and avigation. *All* school subjects are a help in the sense that they reflect good intelligence, ability, and willingness to work. Poor school marks need not be a severe handicap, if you can shoulder the responsibility of studying by yourself and demonstrating your ability to handle the mathematical and scientific tools necessary in air work. To some extent, marked ability in certain lines will compensate for your shortcomings in others, but the person who can't do reasonably well with the kind of mathematics, science, and mechanics usually taught in high school may have tough going as a navigator.

What subjects should you take in school? The answer to this is not too important either. If you like flying, you will probably like these subjects anyhow and will take them to the extent your program permits. First, all high school mathematics is essential. There are parts of algebra, geometry, and trigonometry that every pilot and avigator should know. A college course in calculus will enable you to think clearly about flying problems that might otherwise remain mysterious. This does not mean that the mathematics is constantly used in flying. Quite the reverse; the pilot can solve most of his problems on the flight computer. But sound mathematics will help you under-

stand *why* things are done. The subject gives meaning to otherwise routine tasks.

Then science courses are in order, especially physical and applied science. General science, physics, and chemistry are usually taught in high school. Many schools are introducing courses in preflight training that include all science applicable to flying. A course in physiography or geography may be of help. All shop courses undoubtedly will be, too, as will mechanics, blueprint reading, mechanical drawing, electricity, or radio. College courses in astronomy and meteorology are to the good. Choices are important, as it would be difficult to take all high school courses related to flying. Then there are the preinduction courses, specially designed for young men who will enter the Army at 18. There is more about these later.

It is important for a flier of a commercial transport plane to be able to speak correctly, to express himself freely, to understand and use at least one foreign language. (Spanish is very popular now.) History, English, public speaking, and other school subjects that do not seem to concern flying may be more important than you think. Can you typewrite? There is many a pilot who has had to take time out to master this high school subject.

It's touchy to talk about school subjects in either high school or college. Students are apt to think that the courses should be interesting and entertaining or else they are just no good at all. I suppose teachers would like nothing better than to have every student feel that the course is exactly the thing he wants. This

Official Photograph, U. S. Army Air Forces

THE ARMY AIR FORCES HAVE MANY INGENIOUS DEVICES FOR TRAINING PILOTS. THE NAVI-TRAINER IS ONE OF THEM

is almost too much to hope for. There is a good chance you will have to bring to the course as much as you get from it. If the physics teacher goes right through the text without giving aviation its due credit, don't get sour on the subject. I don't believe there is a chapter in a high school or elementary college physics text which is not important in its application to flying. You may have to dig the relationship out for yourself. It's harder that way but much more satisfying. When you discover that the old formula $\frac{1}{2}gt^2$ tells you a lot about flying besides telling what happens when a man drops a ball from a tower, then you are getting along.

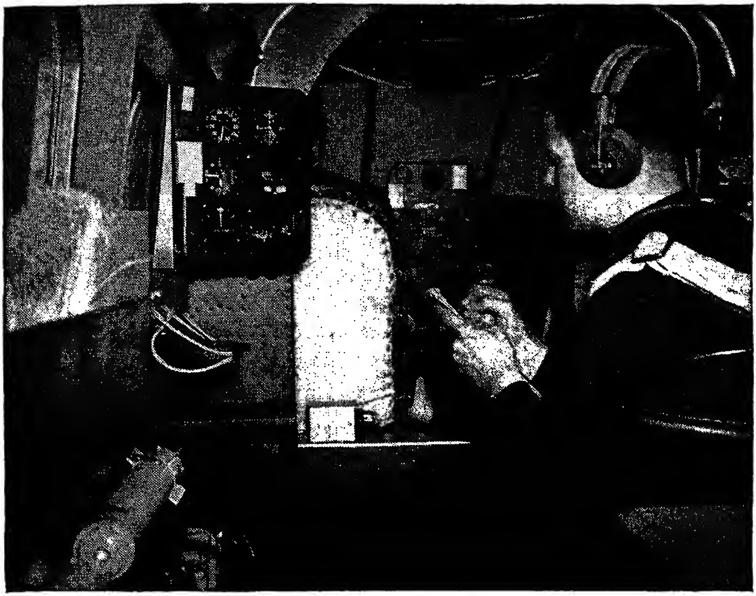
This brings us to a number of things that you can do that are perhaps only indirectly related to your school work. Believe it or not, a pilot once said to me, "My little cousin can tell me lots about planes that I don't know. He can recognize a spot up in the air and tell me everything about it before I can even see what he's talking about." I know lots of young people still in high school who can tell me almost everything about a DC-3, a Boeing 314 A, or an Airacobra that isn't a government secret. Thousands of others build models: historic models, flying models, models that the Army and Navy have used by the thousands in their training program.

This does not mean that anybody with flying as a hobby or who has built a model plane is ready to go into full scale air navigation. But it does mean that the individual is interested, that he is willing to take the time and effort to do things by himself, and that he can learn without someone teaching him.

All of these are, in themselves, worth while, and if useful knowledge about planes and flying comes along with this, so much the better. Even for the youngest air enthusiasts, this matter of having a flying hobby is a sound idea and if you keep at it long enough, its good results can be quickly recognized.

In union there is strength. Often a group of young people with similar ideas can do much more than they could as individuals. That is why clubs have become so popular. Aviation Clubs frequently start at school or in connection with the Scouts or other civil-minded groups. Sometimes half a dozen boys get going with an informal club of their own, meeting at each other's house and working together on projects. Such groups can build a wind tunnel for model planes, or can experiment with more complicated equipment than any one member could afford. Members of such groups help each other and their cooperation gets them a long way. One group of young fellows not much over eighteen worked after school and summers till they had enough money to buy a small plane of their own. By the time they were ready to get their licenses and take wings they had the plane in which to get their needed experience in the air.

It's amazing when you hear the stories of what individuals and clubs have done for themselves and for each other—not the club members who want only to wear a pin and vote at meetings, but the fellows who are really interested in flying. Even before the government offered the assistance it now does, these groups and their members had made excellent progress.



Official Photograph, U. S. Army Air Forces

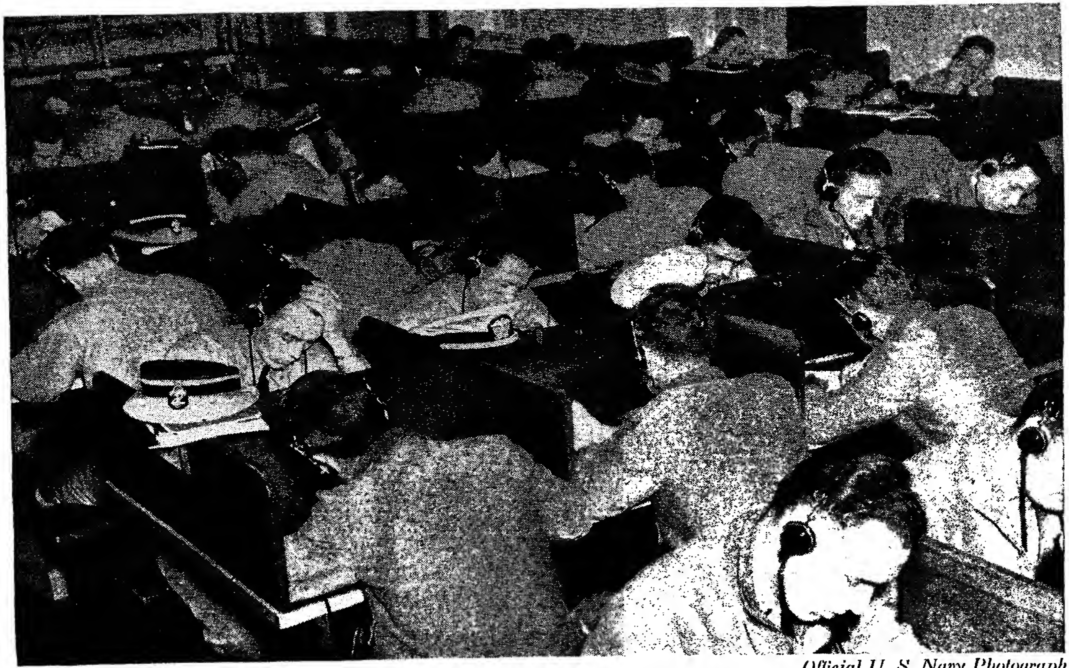
TRAINING FOR NAVIGATION INVOLVES FLYING AS WELL AS GROUND SCHOOL. THE STUDENT NAVIGATOR IS CHECKING INSTRUMENTS WHILE IN FLIGHT

The war has created new needs for manpower. Young men are especially needed. Because the armed forces of the United States are reaching the vast number of ten million men, changes must be made in industry, education, and in nearly everyone's lives. The most important thing about this war is that it is a technical one, a war of motion—fought with tanks, halftracks, planes, and mobile units. It is a war that not only requires men,

but skilled men. The great majority of men in the Army and Navy have skilled jobs to perform and must be specially trained to do these jobs well. There is no need to repeat the importance of flying or to tell you how plane production increases month by month. Thousands upon thousands of skilled young men are needed to handle these war planes. Some, of course, must fly them, but a lot more are needed to service and repair planes, to carry on communication, to move up supplies for them, and to do countless other jobs that are essential to "keep 'em flying."

The Army soon realized that it could not train the men as fast as it needed them, so a section was set up to find ways in which schools could help. The officials of this section studied the work of the Army in detail and noted the kind of men needed. They literally found hundreds of Army jobs where it was important to understand the ways that machines—all kinds of them—operate. Electricity, shopwork, radio, mechanics, aeronautics—all these were found ranking high among the skills the Army needed. This information was gathered into outlines—one on electricity, one on shopwork, and one on machines. There are also outlines on automotive mechanics and radio. These outlines have been sent to all the high schools of the country and many schools are now teaching this material to students in the eleventh and twelfth grades as *pre-induction courses.*

These pre-induction courses directly prepare young men for the Army (and pretty well for the Navy, too). If you are in high school and are interested in them, your principal has the information. The courses in electricity and machines are basic for



Official U. S. Navy Photograph

THOUGH MOST LOCAL RADIO WORK IS DONE BY PHONE, PILOTS LEARN CODE FOR EMERGENCY AND LONG DISTANCE TRANSMISSION

work in the Air Corps as well as other branches of the Army. These courses plus courses in aeronautics, already available in high school, provide a real beginning to a young man's flying education. Those who are more interested in the ground service of the Air Corps will find the courses in automotive mechanics and radio a help. Much of the material of the Automotive Mechanics course is applicable to planes and their engines, and radio is as essential in the air as it is on the ground. There is a special course in radio code practice that is essential for all who expect to fly.

There are other activities to the war effort beside the pre-induction courses, important as this training is. To bring all the other war activities of the school together, the Victory Corps has been organized. This is a voluntary organization that may be started in schools. It has five divisions. The one that will be most interesting to students is the air training division. Students who are active in the school war program may join the Victory Corps. The student must, as a requirement for membership in the air division, take part in the physical fitness program of the school and must take the pre-induction and aeronautics courses just mentioned.

There are a few obvious things to add. While you cannot learn flying or avigation from books, book knowledge may make practical learning easier and may give it more meaning. For those who care to read further, there is at the end of this book a list of volumes pertaining to avigation and its related sciences. These are not stories, but straight adult books treating meteorol-

ogy, radio, instrument flying, etc., in a complete, yet fairly non-technical manner. You probably have questions that could not be answered in this book but which you will find well covered in a complete book on meteorology or instrument flying.

There is no need to remind you that flying requires good co-ordination. Your hand and mind must act together and act quickly. Co-ordination cannot be studied but it can be developed. Anything you do that involves this co-ordination is a help. Learning how to sail a boat, drive a car, run a lathe, or use a typewriter are just such jobs. Many sports require a similar kind of co-ordination if you are to excel. This kind of training, unrelated as it may seem to avigation, is all to the good.

Lastly, if you have the good fortune to be near an airfield or other place connected with aviation, try to make the most of the opportunity. Young people have found ways to be of assistance around hangars and have incidentally learned a good deal about flying in the process. This is quite an art. The boy who makes a nuisance of himself and who is under everybody's feet soon discovers he is not wanted. Airlines and companies under government contract cannot permit outsiders around the premises. Here the fellow from the small town or in the country has an advantage. At small airports or at local hangars the possibility of getting an inside slant on flying is better. The war has placed many restrictions on flying and airfields, and the opportunity to be near planes may have to wait till you are in the armed forces or industry. But whatever the situation, the nearer you get to planes the more you'll learn about them.

This advice is narrowing down. From now on it concerns only those who are about the age of eighteen or who can still look forward to that age. From eighteen to twenty-one is the time to get into flying in earnest. It is the time to bring together all your school training and experience and get into action. This is the time when you can get your training through either the Army or Navy air command. This is the age when you can really spread your wings and fly. If you are looking for help in learning to fly—and keep in mind that complete training up to the airliner level is a matter of four to six thousand dollars—then the next chapter may help you.

20

GETTING YOUR WINGS

You no doubt know the old recipe for making rabbit stew that begins, "First catch your rabbit." The recipe for making a good avigator begins in the same vein—"First learn to fly." Until recently this learning to fly was a costly matter. For this and other equally good reasons there were only 25,000 licensed pilots in 1939, just 35 years after flying became a reality.

But the impact of World War II has aroused a nation from lethargy. No matter what other good may come of this war, it has certainly had the stimulating effect of making the United States air-minded. A direct result of the world conflict has been the inauguration of the CAA pilot training program. If you like initials, just call it CPT (Civilian Pilot Training). CPT has grown by leaps and bounds. Up until recently it offered many young men a chance to learn to fly, and to those who succeeded it offered further training opportunities that included cross-country flying, instrument training, and navigation. Women were at first included in CPT, but because the war has created such an immediate need for men this opportunity has been temporarily withdrawn.

In its CPT program the CAA arranged for colleges to teach

a ground school course in flying in co-operation with a nearby flying school that provides flight training. The program started in an experimental way in 1939 with 13 ground schools and 13 flying schools. You can judge its success by the fact that the end of 1941 saw 674 ground schools and 672 flying schools in operation. The program was designed to turn out 45,000 pilots a year from the elementary course. At least 8,000 a year were to get secondary training and 2,000 or more training in advanced courses. The program was planned to offer complete flight training for the student—and glider training as well.

The CPT was originally planned for young men between the ages of nineteen and twenty-six, but at present they take men a year younger and ten years older. Now most of the CPT training is for the Army and Navy. Very few students are taken directly into the program. For most, contact with the Army or Navy authorities will be the best way to find out about local CPT training. If this can't be done, the CAA in Washington will be glad to give you the facts and direct you to the nearest local office.

If you are not yet eighteen, just plan to continue your schooling and check on the possibility of flight training through the Army, Navy, or CPT when you reach that age. The CPT has given an experimental elementary course in twelve high schools. This course consisted of about 70 hours of ground school and 35 to 45 hours of flight training. The officials were satisfied with the way the high school boys took to the program. They liked their interest, enthusiasm, and adaptability. This high

school program is being extended. If you are now sixteen or seventeen and still in high school, watch out for news of it.

Men over twenty-six are not accepted by the Army or Navy air forces unless they have had extensive flight and technical training. But men between twenty-seven and thirty-seven are accepted in the CPT program where they are trained to be glider pilots, liaison fliers, or service fliers doing important non-combat work.

The CPT must be careful in its selection of students. It is only reasonable to restrict flight training to those physically and mentally fit to fly. There is also the matter of cost. It costs about $400 to give a student preliminary training and nearly an additional $1,000 for secondary training. This is the actual government investment in putting Henry or John or yourself through ground and flying school. And even this is just the beginning. The specialized training that follows these two basic courses involves even greater expense.

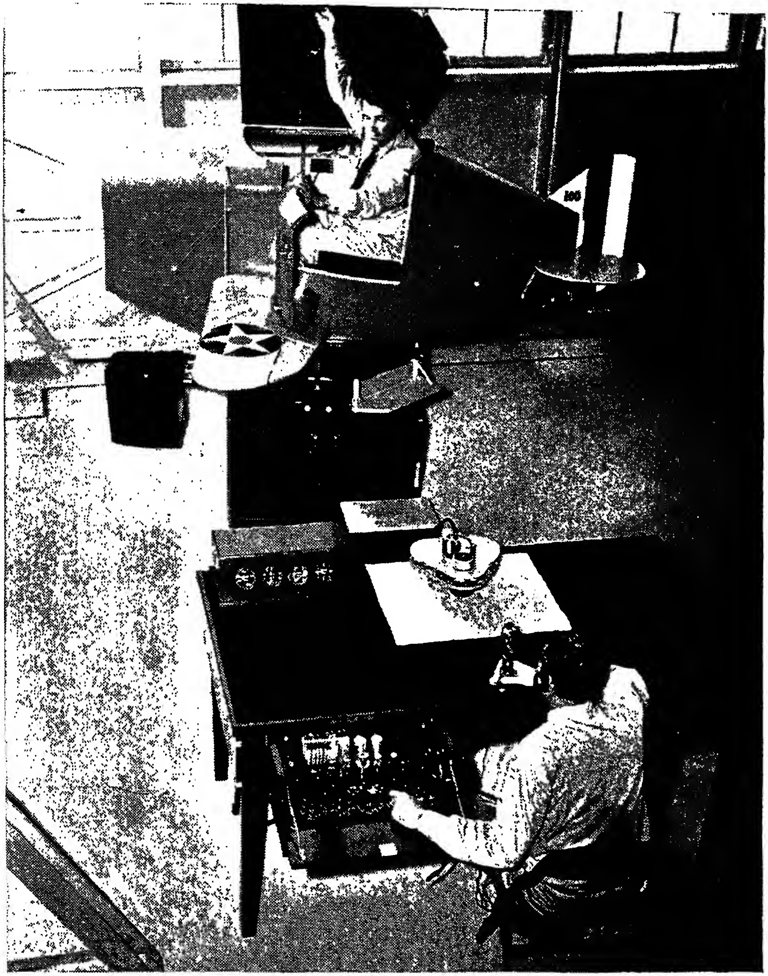
Requirements for CPT students have been changed to meet war conditions and, at present, there is very little difference between the requirements of the Army and Navy fliers and the CPT. In fact the young man over eighteen can enlist directly as a naval flying cadet and his training may begin directly in the Navy flying schools, or the CPT may do the training for the Navy. In this latter case the young pilot may be transferred to Navy schools at the end of any of the CPT courses. He may have only the elementary course under the CPT or may stay till he has instrument and cross-country training. In any case the

student has enlisted in the Navy and has met the Navy physical and other requirements.

The arrangement with the Army is slightly different. Young men who fully meet the Army requirements are usually trained directly at Army fields. However, if a young man applies for Army flight training and fails to meet their strict physical requirements or their exacting tests to get men of the right temperament and mental attitude, another course is open. If no major deficiency is involved, the applicant can turn to the CPT. He will be re-rated and may be accepted for CPT training. Instead of getting combat training, the CPT offers courses in glider piloting and training for auxiliary air service.

Older men who want to take the CPT enlist in the Air Corps Reserve and after training, may be called to these same types of non-combat duty. For none of this training is any formal school education required. Meeting the physical and mental tests is sufficient. Earlier the CPT required two years of college or its equivalent and those courses in science and mathematics recommended earlier are still very desirable for anyone who flies.

The CPT elementary course now consists of about 240 hours of ground school and 35 to 45 hours of flight training in light planes. The secondary course adds another 240 hours on the ground and 35 to 45 more hours in the air, but this time in planes of over 125 horse power. These are eight week courses and are prerequisites to the course in cross-country flying. In these first two courses some study of avigation is included, but it is not till the cross-country course that the advanced student



Official U. S. Navy Photograph

THE LINK TRAINER, WHICH SIMULATES ALL FLYING CONDITIONS, IS USED TO TEACH NAVIGATORS INSTRUMENT AND RADIO FLYING

really gets down to plotting and flying courses with the aids mentioned in this book. The CPT also offers a Link Trainer course that gives the trainee sound instrument training. Some of the students can continue their studies and become instructors.

This brings us to the air forces of the Army and Navy as a second place where air training may be obtained. Here you can start from scratch if you are qualified, or you can continue work started under the CPT. Both the Army and Navy have plans whereby a qualified man of eighteen can enlist and perhaps continue his college training till the end of the year, or till he has completed courses that are part of preflight training. The Army and Navy, of course, run their own training centers that include all ground and flight work as well as military instruction.

The Army was formerly less strict in its educational requirements than the CPT. Now requirements are generally the same. You are required to take a qualifying examination which implies that the person with less schooling has more to make up by studying himself. The Army suggests that it is an advantage to have taken in high school or college the mathematics, science, and other pre-induction courses previously mentioned. The physical requirements are essentially those of good health, good vision, good hearing, normal height and weight, together with the usual requirements of good heart, lungs, etc.

Basic training for all aviation cadets is the same at the start, but after preliminaries have been mastered, there is the

opportunity for specialization. One of these fields of specialization is air navigation. The navigator on a bomber or large Army transport plots the course to and from the objective and gives flight directions to the pilot. He keeps the flight log book and, during an attack, serves as a gunner.

The navigation course is given at Mather Field, Cal., Turner Field, Ga., and at a number of other centers. The course lasts 24 weeks and includes a careful and thorough study of all the topics about which you have read. Dead reckoning, radio navigation, celestial navigation, meteorology, instrument study are all included.

Everyone is familiar with the thorough training that the Army and Navy give their pilots. The cost of such training is so much higher than an average young person could afford that, until the CAA started its program, there was practically no other way to learn to fly—especially with large planes—than in the Army and Navy. That is probably why the airlines have consistently taken as pilots men with military experience. Until this year Army or Navy training was almost essential in securing an airline pilot's job. Now the airlines are also drawing men from the ranks of CPT instructors. Since it is possible for a CPT student to work his way right up to an instructorship, this may now be a second route to the airlines.

When people think of a pilot, they usually have in mind either an Army or Navy flier or the man at the controls of the giant commercial planes. Commercial flying is recognized as the tops in peacetime aviation. Airline pilots have important respon-

sible jobs. They are well paid. They like their work and are all experts at it. To become a pilot for a major airline is an ambitious task. The opportunity is open to all young men (and perhaps some day women will have a chance at being more than hostesses). But you cannot go directly from school to the airlines—at least not to their pilot training schools. That is why either the armed forces or the CPT offer the best background for men who want to make a career of commercial flying.

Each airline has its own specific arrangements for employment and pilot training, but the men they turn out are all uniformly good. First of all the CAA sets strict requirements that all airline pilots must meet. Secondly, all airlines are envious of their records of safety and efficiency and will spare nothing in their training that contributes to these ends. Let us look at the TWA as an example.

To qualify for the Student First Officers' School at Kansas City the applicant must be a citizen of the United States between the ages of twenty-one and thirty-two. He must have an acceptable personality and appearance with no noticeable speech defect. Minimum height is 5 feet 7 inches. Physically the applicant must be in excellent condition as determined by a careful medical examination. Two years of college or the equivalent is required as an educational qualification, with mathematics, science, mechanical drawing, Spanish, typing, and geography as desirable school subjects. Lastly the applicant must have a Commercial Pilot's Certificate and an Instrument Rating with at least 600 hours of solo flying. This last requirement means

a thorough grounding in flying theory and practice as the tests for a commercial certificate and an instrument rating are both strict.

The applicant submits a written application and is usually interviewed by a divisional chief pilot. When tentatively accepted, the company provides free transportation for the pilot to Kansas City where the real examination begins. Through interviews and several types of tests, the company gets an impression of the personality and abilities of the applicant. Personality is important, as airline pilots are in constant contact with passengers whose safety and comfort are given first consideration. To be at ease with people and to inspire their confidence is important for an airline pilot. Next the medical examiner checks and rechecks the applicant's physical condition. If defects are minor, he may be accepted subject to having them corrected. Finally the chief pilot goes over all the data, talks with the applicant, and makes his decision.

Our applicant must be accepted, if we are to follow him through his training program. So let's tell him the good news and go along with him while he secures his necessary equipment. He obtains copies of the TWA manuals, covering all equipment, operations, and procedures, and a copy of the Civil Air Regulations. He receives a navigation kit that contains sectional charts, D-F charts, and instrument approach charts. He gets a log book and pilot training manual, a flight calculator, and a set of headphones. Next he purchases his uniform, a few essential pieces of equipment, and he is ready to start, after

he fills out a dozen or so forms and applications required by law and company rules. His pay begins as soon as he is accepted.

Student First Officer starts right down at a ground school. Even though each beginner has had long experience in the air, the first phases of his training are entirely at the desk. Our student finds himself studying in a small class with about 15 other men. The curriculum covers everything needed to bring the would-be pilot right up to the minute on the equipment and methods used by airlines. First he studies in detail all the equipment on the plane till the cockpit of a DC-3 is as familiar as his own bedroom. He learns to know every control and switch, how and when it is used, and the limitations of its operation. He has lectures on the special variable pitch propellers used on airliners. The student learns about hydraulic systems that control the brakes, flaps, and control surfaces. He knows how to handle these normally and in emergencies. Since the comfort of passengers is essential, the pilot learns the care and use of the heating and ventilating systems of the plane. He is instructed in the use of special equipment such as the de-icers. He learns about every part of the plane from the seats and berths to the radio compass loop.

The course reviews all the pilot already knows about air navigation—and adds a good deal more. There is special emphasis on the use of the automatic radio direction finder and the use of flight calculators that cut down the arithmetic needed for dead reckoning calculations. There are lectures and demonstrations on radio so the First Officer can not only use his equip-

ment but can locate trouble and make some repairs during flight, if an emergency should arise.

Last of all, the ground course goes into all the rules and regulations for flying. There are the company regulations, communication procedures, and Civil Air Regulations. Regulations cover the use of Airway Traffic Control and the preparation of flight plans, clearance papers, and reports. These flight plans are important and the student plans flight after flight under all conceivable conditions: estimating time, distance, fuel consumed, and power needed. Students get code practice, if they are not already proficient. They must be able to send at a minimum rate of eight words a minute. Code is more reliable than voice during storms or static. This makes it valuable on trans-oceanic flights where stations are far apart. Code is not regularly used on the domestic airlines.

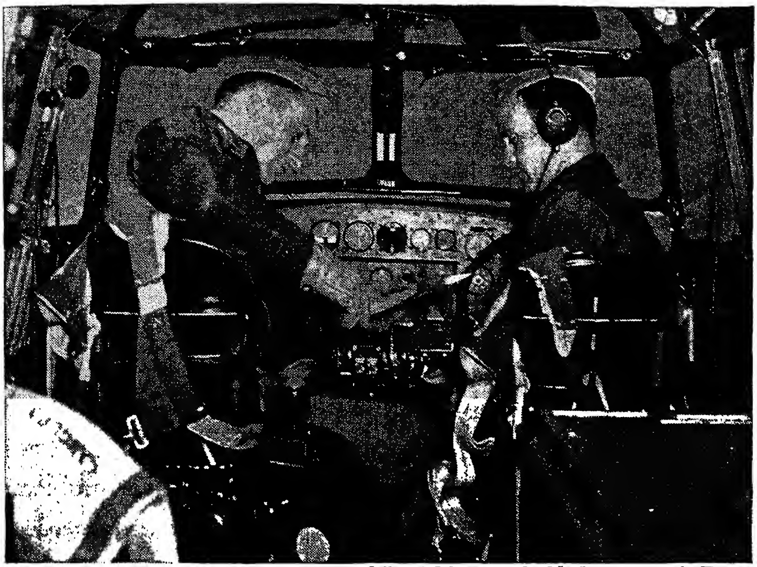
This seems a heavy enough program but it isn't all. The student spends at least five hours in the Kansas City airport control tower to get a view of its operation and to have an even clearer picture of the correct landing and take-off procedures. The course also includes 15 hours of meteorology that lays special stress on weather reports, air mass analysis, upper air reports, and weather analysis. When all this is finished the student is ready for his final written examinations covering all the work in the Student First Officer Ground School.

While he is busy in the ground school, the Student First Officer manages to get in at least 15 hours in the Link Trainer. This refreshes the pilot's knowledge of instrument flying and

introduces him to more advanced methods. A wind simulator connected with the Link Trainer duplicates the conditions of drift occurring in all weather the pilot may encounter. In the trainer the student can use his instruments exactly as he would in the plane. He can make turns, climb, glide, stall, and spin. He can take off, climb, fly a prescribed course, glide, and land. His trip will be recorded automatically and the student can see from the record the mistakes he made.

Next the student goes into a period of transition training during which he learns to handle the type of planes used by TWA. Whatever his previous experience, he learns to handle the big Douglas transports. He practices take-off, turns of all kinds, use of power, adjustment of the variable pitch propellers. He climbs, spirals, practices instrument approaches, lands, and taxis. Finally the student is ready for the air. He is assigned to a plane as a "fourth crew member." He carries out his duties under the direct supervision of the First Officer who reports on the student's progress. After at least 50 hours of guided work in the plane the student's record is forwarded to the chief pilot. If all is satisfactory, the student will leave his training period behind and enter on his duties as a probationary First Officer. For the first three months he will be assigned to the Kansas City-Albuquerque Division, close to his home station. Later he will be transferred to some other division of the airline.

During the year of probationary employment, the new First Officer is constantly checked by his superiors. The Captain of the plane to which he is assigned reports on his fitness at least



Official Photograph, U. S. Army Air Forces

THESE MEN ARE AT THE CONTROLS OF A DOUGLAS B-18A

three times monthly and makes suggestions for the improvement of his work. The Captain will give him instruction and pointers as he goes along—all helping the First Officer to improve his flying technique.

At the same time the new officer must continue his studies. At this stage he gives his attention to the TWA navigation course which he must complete within six months. You'll recognize the topics at once—earth co-ordinates, aeronautical charts, compass deviation and variation, course plotting, ground and air speed problems, dead reckoning, and many others. Then

there is advanced work in the Link Trainer and, if by this time six months have elapsed, it is time for the first of the series of semi-annual instrument checks. His Captain will test the First Officer on all phases of instrument and radio flying. Should the officer fail this check, he is grounded till he can have enough practice to overcome his deficiencies.

Now comes a course of 20 hours or more in the Stinson Instrument Training Planes, where the First Officer gets actual practice in instrument and radio D-F flying. He must execute maneuvers within three degrees of direction. He must follow and identify radio beams and generally become as proficient as possible in instrument flying. Lastly, he is required to attend weekly meteorological forums where current weather problems are discussed. At the end of the probationary year a board of chief pilots and captains examines the First Officer's record. If after this time he has not reached standards, in spite of the cost of training, the pilot may be "washed out." The board may recommend additional training if there is some specific defect in the probationer's flying. If everything has gone well, the First Officer receives a permanent appointment.

It has taken about a year and a half to convert an experienced pilot into an airline pilot. By this time about 10% of the carefully selected group that started First Officer training has been "washed out." They were all good fliers to start with and even those who failed are good. Perhaps they continually disregarded minor rules. Perhaps they never developed the confidence that an airline pilot must have. Those who have come through are a

special kind of pilot; men who like and who can handle the big planes.

The First Officer is co-pilot and most of these young men do not stop here. They continue their training. The next step is to the rank of Captain—full commander of an airliner. You can take my word that the training is just as rigorous—ground school, navigation, more meteorology, radio code practice, and lots more. Then flight training and checks; more CAA tests, physical examinations, and finally the top.

Aviation is for the young—only they have the stamina to come through a program such as that required by the airlines. By the time a man has become the Captain of an airliner he can fly—and there is no doubt about it.

You might think these airline pilots would be bored with flying after all their hours in the air, but they are not. Many of their flights are routine. Occasionally the weather acts up and they must use all their knowledge of navigation to keep on the course and on schedule. These experienced pilots admit that avigation gives them their exciting moments in flight. That is why it's a pilot's holiday when he gets a chartered trip—to take the plane on a special flight where there are new routes to navigate and new problems.

Once you have the thrill of controlling a plane in the air you are ready for the next and more enduring stage. You only learn to fly once but you are always learning to navigate. There are new routes, new methods, and new places to go. First get your wings and then see where they can take you.

There is a lot of satisfaction when your flying figures check with your dead reckoning and when you fly the course you plotted exactly as planned. If you don't think air navigation has a thrill to it—just try it some time. Thousands of other young Americans are doing just that.

GLOSSARY

ABSOLUTE HUMIDITY—The actual amount of water vapor in a unit volume of the air.

ACCELEROMETER—An instrument measuring the accelerations of an aircraft as compared to the normal pull of gravity.

ADIABATIC—An internal heating or cooling process during which no external heat is added and no internal heat is removed from the air mass concerned. Adiabatic changes of temperature are a result of compression or expansion accompanying an increase or a decrease of air pressure.

AERIAL—*See* Antenna.

AGONIC LINE—The line of zero magnetic variation.

AIR MASS—An extensive body of air within which temperature and moisture content at any horizontal level are uniform.

AIRPORT TRAFFIC CONTROL—The control authority at an airport, responsible for the safe take-off and landing of planes. Direction and instruction is given pilots by radio.

AIRSPEED—The speed of a plane relative to the air, independent of the motion of the air.

AIRSPEED INDICATOR—A navigation instrument for measuring the air speed of a plane. The instrument readings must be corrected for temperature and pressure.

AIR TEMPERATURE—The temperature of the air at the altitude of the plane.

AIRWAY TRAFFIC CONTROL—The agency of the Federal Government responsible for air traffic on the airways. All flight plans must be approved by A.T.C. before a flight can be made.

AIRWORTHY—The condition of a plane when fit and safe for use under normal flying conditions.

ALTIMETER—An instrument measuring height of the plane utilizing the principle that air pressure decreases with altitude. A refined form of aneroid barometer.

ALTO-CUMULUS—A fleecy type of large whitish or grayish clouds partly shaded, often in rows or loose layers.

ALTO-STRATUS—Stratus clouds, similar to cirro-stratus, but heavier and lower.

ANEROID BAROMETER—A non-mercurial barometer measuring changes in atmospheric pressure by the movements of the elastic cover of a metallic diaphragm.

ANTENNA—A conductor used with a transmitter to send out radio waves, and with a receiver to intercept the waves; often a long straight wire or a loop. The loop antenna is an integral part of the radio compass and direction finder.

ANTICYCLONE—An area of high barometric pressure from which winds blow outwards in a clockwise direction. A "high."

ANTITRADES—The westerly winds blowing at high altitudes above the trade winds.

ARCTIC FRONT—The line of contact between the cold air flowing directly from the arctic and warmer polar maritime air.

ARTIFICIAL HORIZON—A gyroscopic instrument showing the position of a plane in relation to a line held horizontal by gyroscopic action. An important flying instrument, also called the gyro-horizon.

BANK—To tilt a plane so its wings are no longer horizontal as it makes a turn.

BEACON—A revolving light guiding planes along the airways or a low power radio transmitter sending out a distinctive signal.

BEAM—The directional radio signal heard in the equisignal zone: blending together of the A and N quadrant signals.

BEARING—A direction of a landmark or destination expressed as an angle measured clockwise from true north.

BLIND FLYING—Flying when ceiling is low and ground cannot be seen: using readings of instruments and radio aids and a general knowledge of the plane and the region.

CEILING—The vertical distance from the ground to the bottom side of the cloud layer.

CEILING-LIGHT PROJECTOR—A light for determining the height of the ceiling at an airport by throwing a spotlight on the clouds.

CELESTIAL NAVIGATION—The method of determining position by observations of the sun, stars, or other celestial bodies.

CHART—A map specially designed for use in navigation showing latitude and longitude, elevations, compass roses, physical and cultural features, etc.

CIRCLES, GREAT—A circle whose plane passes through the center of the earth dividing the earth in half, as the equator and the meridians.

CIRRO-CUMULUS—Small, white, rounded clouds at a high altitude; when grouped in rows these form a mackerel sky.

CIRRO-STRATUS—A layer of high stratus clouds or haze.

CIRRUS—Light filmy clouds of the highest cloud type consisting of minute ice crystals.

CIVIL AERONAUTICS ADMINISTRATION—The CAA is under the Department of Commerce. Its function is to develop and regulate air traffic.

COLD FRONT—A zone or line along which cold air is replacing a mass of warmer air.

COMPASS, CALIBRATION—The process of establishing the deviation of a compass on various headings of the plane.

COMPASS, COMPENSATION—A method of applying small magnets near the compass to neutralize the magnetic forces of the plane's structure and equipment.

COMPASS COURSE—*See* Course, Compass.

COMPASS HEADING—*See* Heading, Compass.

COMPASS, MAGNETIC—An instrument showing magnetic north and indicating the angle between it and the direction a plane is going.

COMPASS ROSE—A graduated circle printed on aeronautical charts as a means of measuring direction.

COMPUTER—A device for rapidly solving problems of navigation. It consists of a circular slide rule and wind drift computer.

CONE OF SILENCE—An area, shaped like an inverted cone, directly above a radio range station where the station's radio signal fades out.

CONTACT FLIGHT—A flight navigated by reference to a map and visible landmarks. In contact flight, the pilot must be able to see the earth at all times and recognize conspicuous landmarks.

CONTOUR INTERVAL—The vertical distance between two successive contour lines. Contour lines may show 20, 50, 100, 500 or 1,000 foot intervals.

CONTOUR LINE—A line on topographic or aeronautical charts connecting all points at the same elevation above sea level.

CONVECTION—Movements of the air, usually upwards, produced by heating or pressure changes. Convection is essential to the formation of several types of clouds, especially the common cumulus type.

COURSE—The course of a plane is its path in flight measured clockwise from a line of reference. True course (TC) is the angular direction of the course measured from true north. Magnetic course (MC) is the direction of the course measured from magnetic north. Compass course (CC) is the direction of the course measured from compass north. A course is always the direction of a rhumb line. "On course" means flying as planned or on the beam.

CULTURAL FEATURES—A term applied to the cities, highways, railroads, and other works of man, usually shown on aeronautical charts by black symbols.

CUMULO-NIMBUS—A mass of low gray clouds from which rain or snow is falling.

CUMULUS—A massive white cloud forming at heights of 5,000 to 15,000

feet, having a flat base and piled-up rounded outlines. Cumulus clouds mark ascending convection currents.

CYCLONE—An air mass of low barometric pressure around which winds blow in a counter-clockwise direction. It is commonly called a "low."

DEAD RECKONING—The method of finding a plane's position or course from a knowledge of its distance and direction from a known point; the method of calculating the factors of a flight before take-off.

DEVIATION—The difference between the compass heading of a plane and the actual magnetic heading, due to conditions within the plane that affect the compass.

DEVIATION CARD—A card showing the correction to be added or subtracted from a compass heading to give the correct magnetic heading.

DEW—Water vapor from the air condensed on objects cooler than the air, especially at night.

DEWPOINT—The temperature to which an air mass must cool before condensation of the moisture in it will begin.

DIRECTIONAL GYRO—A navigation instrument using the inertia of the gyroscope for measuring the turn of a plane to the right or left.

DRIFT ANGLE—The angle between the heading of a plane and the track over the ground, as determined by observation through a drift sight or from radio bearings.

DRIFT SIGHT—An instrument used to determine the drift angle.

EDDY—A local irregularity in a wind producing gusts, lulls, and a general turbulent condition.

FALL WIND—A wind, usually warm and dry, blowing down a mountainside.

FIX—The position of a plane determined by the navigator by the intersection of two or more lines of position or bearings.

FOG—A cloud on the surface of the earth. Fog consists of many droplets of water, so small that they cannot be easily seen. The droplets are too light to be affected by gravity.

FREQUENCY—The frequency of alternating current is the number of cycles per second. The frequency of a radio wave is the same as the frequency of the alternation of the current that produced it. It is the number of complete waves that pass a point per second.

FRONT—The boundary between two different air masses. *See* Cold Front and Warm Front.

FROST—Groups of ice crystals formed when the moisture of the air condenses on objects at a temperature below freezing.

FUSELAGE—The body of the plane to which the wings and tail are attached.

GNOMONIC PROJECTION—A map projection that shows the arcs of great circles as straight lines on charts. It is used in long distance navigation.

GREAT-CIRCLE BEARING—The direction between two points following the great circle that passes through both places. It is the shortest distance between the two places.

GROUND SPEED—The speed of a plane relative to the ground. Air speed corrected for drift.

GUST—A sudden, brief increase in the force of the wind. Most winds near the earth's surface display alternate gusts and lulls.

GYRO-HORIZON—*See* Artificial Horizon.

HAIL—Balls of ice, usually in concentric layers, formed as rain drops are carried aloft by an updraft.

HAZE—A decrease in the transparency of the atmosphere caused by dust or salt particles in the air.

HEADING—The direction in which a plane is pointing. Measured from true north, it is a true heading (TH); if reckoned from magnetic north, it is a magnetic heading (MH); if reckoned from the compass, it is a compass heading (CH).

HIGH—An area of high air pressure around which winds are moving clockwise and outward. An anticyclone.

HORSE LATITUDES—The regions of calm, variable winds and high pressure, north and south of the trade wind belts.

HUMIDITY—The amount of water vapor in the air. Absolute humidity is the amount of water vapor per unit volume of air. Relative humidity is the ratio of water vapor actually present in the air to the amount needed to produce saturation at that temperature.

HURRICANE—A tropical cyclone originating in the Caribbean or in the vicinity of the West Indies.

HYGROMETER—An instrument for measuring relative humidity.

INDICATED AIRSPEED—The airspeed read from the dial of the airspeed indicator, not corrected for errors of temperature or pressure.

INSTRUMENT FLIGHT—A flight in which the course is determined by calculation and the use of navigation instruments, because of poor visibility.

INTERPOLATION—The processes of finding or inserting an intermediate number in a series, as with numbers in a table, distances on a chart, etc.

ISOBAR—A line on a weather map drawn through places having the same barometric pressure. Usually drawn with pressure reduced to sea level reading.

ISOTHERM—A line on a weather map drawn through places having equal temperatures. The freezing, or zero, isotherms are most commonly used.

LAMBERT CHART—A chart based on the Lambert conic projection, as are the aeronautical charts of the United States Coast and Geodetic Survey.

LAND AND SEA BREEZE—The breeze that, along the coast, blows from the land toward the water by night (land breeze) and from the water toward the land by day (sea breeze).

LINE SQUALL—A belt of squalls and thunderstorms marking an advancing cold front.

LOW—An area of low barometric pressure, around which winds blow clockwise and toward the center. *See* Cyclone.

LUBBER LINE—A fixed line on the dial of the compass or other navigation instrument, oriented parallel with the plane's axis.

MACKEREL SKY—A loose network of cirro-cumulus or alto-cumulus clouds in diagonal rows like the design on a mackerel's skin.

MAGNETIC NORTH—The north pole of the earth's magnetic field, located in Canada Lat. 71° N. Long. 96° W.

MAGNETS, COMPENSATING—Small magnets placed in a compass to correct for deviation.

MAYDAY—The S O S of the air; the radiophone call for help. It is the English pronunciation of the French "m'aider" meaning "help me."

MERCATOR CHART—A chart showing latitude and longitude as straight lines, intersecting at right angles. Used for navigation of ships and for many general purposes.

MERIDIAN—A great circle formed by a plane passing through the earth's axis: hence, meridians always pass through the north and south geographic poles.

MOUNTAIN AND VALLEY BREEZES—The wind that, in mountainous regions, usually blows up the slopes by day (valley breeze), and down the slopes by night (mountain breeze).

NAUTICAL MILE—The distance of one degree of latitude or one degree on any great circle—6,080 feet or 1.15 statute miles.

OCCLUDED FRONT—The front formed as the cold front in a low overtakes the warm-front.

OCCLUSION—The process whereby the warm air in a low is forced from the surface by colder air.

PILOT BALLOON—A small free balloon released by the meteorologist and carefully observed. Its drift indicates the wind direction and velocity aloft.

PILOTING—The directing of an airplane by means of visible landmarks.

PLOT—To locate a position or course on a chart.

POLAR CONTINENTAL AIR—An air mass originating over land or ice in the polar regions. It is cold, dry, stable air.

POLAR FRONT—The contact between a polar air mass and warmer moist air.

POLAR MARITIME AIR—Polar continental air that has been modified by

passage over the warmer oceans. This makes polar maritime air more humid and less stable than polar continental air.

PRECESSION—The motion of a rotating gyroscope orienting it at right angles to any force that tends to tilt its axis.

PRECIPITATION—All forms of condensed atmospheric moisture in liquid and solid form: rain, snow, hail, dew, and frost.

PREVAILING WESTERLIES—The belts of winds lying north and south of the horse latitudes.

PROJECTION—Methods of representing the earth's meridians, parallels, and land forms on a chart. Some type of distortion is always involved in these processes.

QUADRANT—One of the four regions or signal zones around the radio range station in which the N and A signals are clearly heard.

RADIATION FOG—A fog caused by the cooling of air near the ground on clear nights by the process of radiation.

RADIO NAVIGATION—The method of navigating a plane by means of radio beams and other radio aids to navigation.

RADIO RANGE—A path for guiding planes along a signal beam produced by the fusion of A and N signals sent out from the directional aerials of the radio range station.

RATE-OF-CLIMB INDICATOR—An instrument indicating the rate of ascent or descent of a plane as differences in air pressure affect the mechanism.

RELIEF—Differences in elevation on the surface of the earth; represented on charts by contour lines, gradient tints, or hachures.

RHUMB LINE—A line that crosses a series of meridians at the same angle. On a Mercator chart, a rhumb line is straight; on a Lambert chart, it is a curved line.

RIGIDITY—The tendency of the axis of a rotating gyroscope to retain its direction irrespective of any rotation of the instrument.

RUNNING FIX—A fix, or position, established while the plane is in motion. Hence the observations must be corrected by dead reckoning.

SLIPSTREAM—The blast of air driven back from the propeller of a plane.

SMALL CIRCLE—Any circle on the surface of the earth not a great circle. One whose plane does not pass through the center of the earth.

SOUNDING BALLOON—A small, free balloon carrying a set of self-registering weather instruments.

SQUALL—A sudden blast of wind of higher velocity than the average.

STANDARD ATMOSPHERE—The atmosphere reduced to standard conditions for purposes of comparisons. The standard atmosphere has a barometric pressure of 29.92 inches and a temperature of 59° F. at sea level.

STANDARD PARALLELS—The two parallels of latitude on a Lambert projection, where the cone intersects the sphere. The standard parallels for the air charts of the United States are 33° and 45° N. Lat.

STATUTE MILE—The mile normally used in land measure—5,280 feet.

STRATOSPHERE—The upper region of the atmosphere where the temperature is practically constant. The height of its base varies with latitude and with the seasons.

SWINGING THE COMPASS (THE SHIP)—The process of adjusting the compass and partly correcting for deviation.

SYNOPTIC CHART—A chart, or weather map, showing the meteorological conditions over the country at a given time.

TAILWIND—A wind blowing parallel or directly on the tail of a plane, thus increasing the ground speed.

TRACK—The actual path of the flight of a plane over the ground.

TRADE WINDS—Belts of constantly blowing winds on either side of the equatorial belt of calms.

TRIANGLE OF VELOCITIES—A triangle whose sides represent the wind speed, the air speed of the plane, and the ground speed of the plane. Used in calculation of wind correction angle.

TROPICAL MARITIME AIR—Any air mass that originates over a warm

ocean area. Such air has a high surface temperature and high humidity.

TROPOPAUSE—The point in the atmosphere at which the fall of temperature with altitude ceases. The base of the stratosphere.

TROPOSPHERE—The lower regions of the atmosphere where temperature generally decreases with altitude. The atmosphere up to heights of 6 to 9 miles.

TURBULENCE—An irregular condition of gusts and lulls produced when winds blow over uneven land forms or when air currents pass each other in different directions or at different speeds.

VARIATION—The angle between the true north and the magnetic north measured in degrees east or west of true north.

VECTOR—A line which, by its length and direction, represents the strength of a force and the direction in which the force is acting.

VEERING—A clockwise change in wind direction.

VENTURI TUBE—A short tube of varying diameter through which a flow of air causes a pressure drop at the smallest section of the tube.

VISIBILITY—The maximum distance in miles, toward the horizon, at which landmarks can be distinguished.

WARM FRONT—The contact of the forward edge of an advancing mass of relatively warm air which is displacing a colder air mass.

WAVE LENGTH—The distance between two successive crests of a radio wave.

WIND-CORRECTION ANGLE—The angle between the track of a plane and its heading. The angle the plane must be turned into the wind to correct for drift.

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